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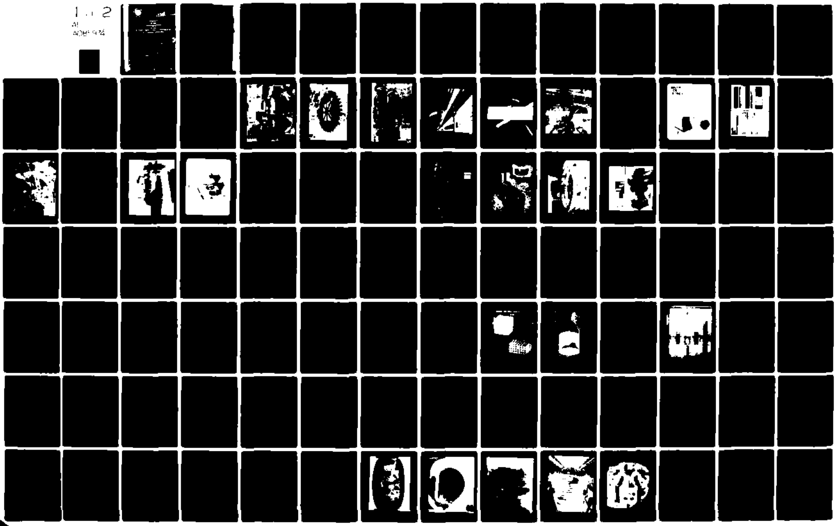

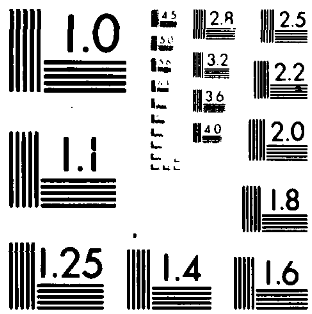

MICROCOPY RESOLUTION TEST CHART
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Superconductivity; Superconducting Magnets

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This publication contains summaries of recent Federally funded research and development work in the fields of superconductivity, superconducting magnets and superconducting motors. This was presented at an IAPG Superconductivity Technical Session held at the Naval Research Laboratory 16 April 1980. The material included is author prepared.

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Summary of the PROCEEDINGS of the SUPERCONDUCTIVITY TECHNICAL EXCHANGE MEETING.

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11 16 Apr 80

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SUPERCONDUCTIVITY PANEL
OF THE
INTERAGENCY ADVANCED POWER GROUP

MEETING DATE: 16 APRIL 1980
NAVAL RESEARCH LABORATORY
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411811

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3

FOREWORD

This document contains summaries, reproductions of visual material detailing the material presented by speakers at The Superconductivity Technical Exchange Meeting.

The meeting was part of the Interagency Advanced Power Group Superconductivity Panel held at the Naval Research Laboratories in Washington, DC. The meeting was hosted by Dr. Donald U. Gubser of NRL.

THE INTERAGENCY ADVANCED POWER GROUP

The Interagency Advanced Power Group (IAPG) operates under a joint agreement signed by the United States Army, United States Navy, United States Air Force, National Aeronautics and Space Administration, and the United States Department of Energy.

The IAPG is a mechanism for the timely and relevant exchange of programmatic and technical information for government scientists, engineers and R&D managers who have a direct interest in advanced power technology, research and development. Power, as defined by the IAPG Charter, encompasses energy sources, conversion techniques and devices and transmission systems or components exclusive of aeronautical/astronautical propulsive power. The goal of this information exchange is the reduction of unplanned duplication of R&D effort.

The IAPG presently consists of the following Working Groups and Panels: Electrical (including the Power Conditioning and Superconductivity Panels); Magnetohydrodynamics; Chemical; Mechanical; Nuclear, TE, TI; Solar (composed of the Photovoltaic and Thermal Panels); and Systems. Information exchange is carried out through periodic meetings of the IAPG members in their respective Working Groups and Panels, the distribution of the technical minutes of these meetings and the distribution of IAPG Project Briefs that periodically report the progress of programs funded by the supporting agencies.

The Power Information Center (PIC) is operated by Franklin Research Center for the Interagency Advanced Power Group and acts as the technical secretariat for the organization. For more information concerning this document or the IAPG, please contact: Power Information Center, Franklin Research Center, 20th and Race Streets, Philadelphia, PA 19103, 215-448-1674.

WELCOME ADDRESS

Captain E. E. Henifin
Commanding Officer
Naval Research Laboratory

On behalf of the Naval Research Laboratory, it is my pleasure to welcome you to the Laboratory and to this annual meeting of the Superconductivity Panel of the Interagency Advanced Power Group. For some of you, this may be the first time at NRL and we hope that during your visit you will be able to see some of our facilities. The tour scheduled for tomorrow morning should provide this opportunity.

Looking over the list of attendees and speakers, it is a pleasure to recognize the wide range of activities that are represented here today and, in particular, the large contingent from the Department of Energy Laboratories.

NRL is a firm believer in meetings, conferences, workshops, etc., which emphasize free discussion and exchange of ideas, but to be successful, full participation is required - not just the presentors - but all of you as listeners, as questioners - as idea generators.

The phenomenon of superconductivity is receiving much attention today, especially in light of our current energy crisis. The resistanceless flow of electrical current has spurred many revolutionary ideas for new technologies. In the last 10 to 15 years there has been sufficient understanding and progress in superconducting materials to permit testing of these new concepts. Today many large-scale engineering projects are underway and we appear to be on the threshold of tapping the potential of superconductivity. This meeting today brings together many of the leading scientists and individuals involved with these developments and should provide an up-to-date status report and a prognosis for future expectations.

At NRL we have supported superconductivity research for over 30 years. Today, we have groups working in 1) Superconducting Theory, 2) Superconducting Materials Research, 3) Superconducting Device Development, 4) Superconducting Wire Development, and 5) Cryogenic Refrigeration Studies for cooling both large and small scale devices. The Navy, in general, has an interest in electric ship propulsion using superconducting motors. This research is being pursued at the Naval Ship Research and Development Center at Annapolis and will be reviewed later this afternoon. Work at NRL on Material Research and Wire Development Programs will be reviewed at the end of the day by Dr. D. U. Gubser, host of this meeting.

I'm sure you are all interested in beginning this meeting so I will close my comments and again welcome you to NRL.

HAVE A GOOD MEETING!

LARGE SUPERCONDUCTIVE MAGNETS

Presented by
R. W. Boom
University of Wisconsin

ABSTRACT

Many large superconductive magnets have been successfully operated during the past 15 years. One of the largest magnets is the 800 MJ CERN bubble chamber magnet which is a fully stable pool cooled split solenoid. Current fusion and MHD coils are in the 200 MJ range. All new coils are fully stable with current densities about 2500 A/cm2. Cooling is primarily by pool cooling. A few large coils in the fusion program use hollow conductors cooled with forced flow supercritical helium.

For even larger systems the trend is towards more stability, lower current density and more structure. The scaling law which relates structural mass to required ampere-meters of conductor is:

$$\frac{\text{structural mass}}{\text{ampere-meters}} \propto BR,$$

where B is the field produced and R is a magnet dimension, solenoid radius, for example. The trend is towards less emphasis on unstable magnets; that is, those magnets with inadequate cooling and inadequate stabilizing normal metal matrix are not being used for larger systems.

Larger magnets will become even easier to build due to the fact that more space is available. Reference is made to the Virial Theorem (for magnets) which is a mathematical statement that the structure needed is proportional to energy stored:

$$M_T - M_C > \frac{\rho}{\sigma} E \quad \text{(unidirectional structure)}$$

where: M_T = structural mass in tension

M_C = structural mass in compression

ρ = structural density

σ = average stress

$E = \int \frac{B^2}{2\mu_0} dv$ = energy stored

Thus there is no structural efficiency difference between small and large coils, there is only a difference in more free space available around large magnets.

Estimates for the absolute minimum structure for future full scale base load units can be made with the Virial Theorem based on the stored energy in the magnetic field. Actual structure, because some (wasteful) compressive numbers are always needed, can easily be larger than the Virial Theorem amount. See Table I which follows.

Large magnets in the 6-8 T field range seem adequate for most large systems. System designs tend to optimize at these fields which implies that NbTi alloys are adequate. NbTi alloys cooled to 1.8 K can be used up to 12 T which presents significant competition for Nb_3Sn and any other high field brittle compound.

There appears to be limited scientific need for new and better superconductors. NbTi is a very usable ductile alloy. Nb_3Sn is brittle but tolerant to strain due to precompression during manufacture and cool-down. New conductors would generally be similar. As the various systems approach commercialization the cost and availability questions will predominate. To that end it is recommended that substantial effort be expended to increase current densities and to develop less expensive alloys and compounds. Savings also may be made by increasing usable T_c. Large systems probably will not need higher critical fields than now available. However, higher critical current densities often accompany higher H_{c_2} so research into higher H_{c_2} is still useful for large systems.

Cooling by superfluid helium is potentially very attractive. Very little use has been made of this possibility. Most of the experience to date has been developed by the French fusion program at Saclay in collaboration with the cryogenic laboratory at Grenoble.

Current production in the U.S. of NbTi is about 100,000 pounds per year. The FNAL accelerator project needs about 40,000 pounds total. A similar amount for ISABELLE at BNL represents the major accelerator requirements. For the first time the superconductivity requirements for fully stable non-accelerator uses are predominating the market place. Accelerator requirements of 30,000 A/cm^2 overall in a magnet have kept world-wide attention on the unstable trainable pulsed magnet problem. However the much lower current densities used and planned for MHD, Fusion and Energy Storage will tend to direct most future magnet design research towards fully stable coils.

Acknowledgements

The following were of great assistance in providing information and figures: D. Cornish, LLL; J. Ferrante, GE; M. Lubell, ORNL; R. Smith, ANL; W. Fowler, FERMI LAB; M. Kuchnir, FERMI; R. Thome, MIT; J. Wong, SUPERCON; R. Marsh, WAH CHANG; D. Larbalestier, UW-MADISON; S. Van Sciver, UW-MADISON; E. Gregory, AIRCO; T. DeWinter, MCA.

Table I

Base Load Systems Rated at 1000 MW

Unit	Stored Magnetic Energy	Design* Structural Weight	Virial Theorem* Structural Weight	Estimated NbTi Weight
MHD(1)	10^{10} J	4.6×10^{6} kgrams	1.4×10^{5} kgrams	3×10^{4} kgrams
Tokamak(2)	4×10^{10} J	1.1×10^{6} kgrams	5.6×10^{5} kgrams	7.5×10^{4} kgrams
Energy Storage(3)	1.3×10^{13} J	24×10^{6} kgrams**	1.8×10^{8} kgrams***	3.4×10^{5} kgrams

* Aluminum alloy structure in all three examples
** Dewar and struts which are not energy containment structure
***This structural mass is <u>not needed</u> because in-situ bedrock is used as structure

1. Scaled from 600 MW unit designed by A. M. Hatch, et al, "Design of Superconducting Magnets for Full-Scale MHD Generators," Advances in Cryogenic Engineering, Vol. 23, page 37, (1978), Plenum Press

2. Scaled from 725 MW unit design by University of Wisconsin, NUMAK-330, March 1979

3. Scaled from 1000 MWh unit to 3000 MWh unit used 3 hours per day at 1,000 MW average power, University of Wisconsin design, Volume I, July, 1974.

LARGE SUPERCONDUCTIVE SYSTEMS

MATURE INDUSTRY

- 20 YEARS OLD
- GOOD OPERATING RECORD
- HUGE PROJECTS
- 100,000 LBS/YR NbTi

PRESENT TASKS

- ENGINEERING
- COST EFFECTIVENESS

PRESENT EMPHASIS

- 0-12 TESLA
- COPPER + FILAMENTARY NbTi
- MONOLITHIC OR CABLES
- POOL COOLING, 4.2 K
- FORCED FLOW, ΔT

HIGH ENERGY PHYSICS

HISTORICAL LEADER

BUBBLE CHAMBERS

- 12-15 FT DIA.
- 400 MJ
- $J_t \sim 1000$ A/cm^2
- POOL COOLING
- FULLY STABLE, I^2R<HEAT REMOVAL

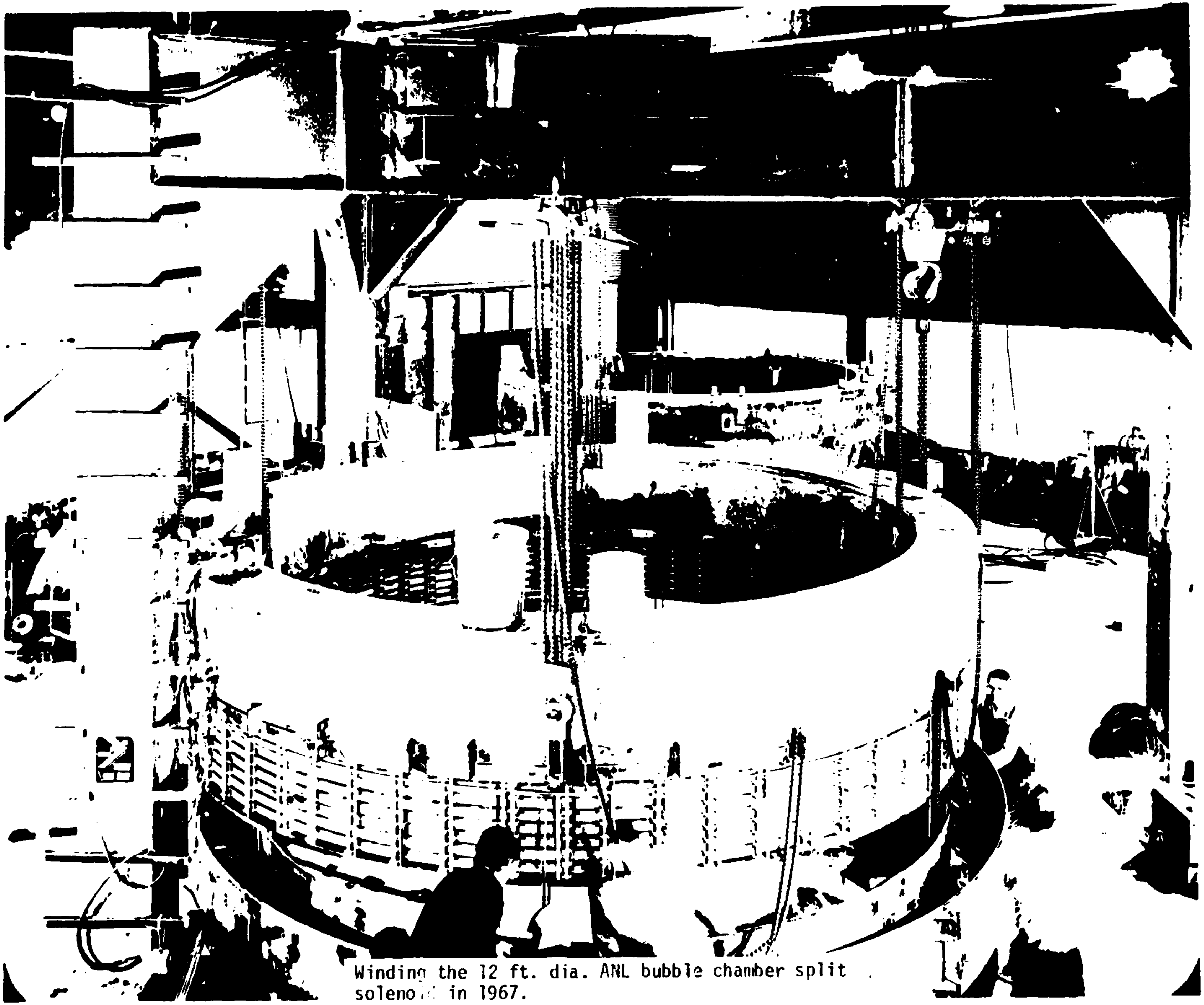
ENERGY DOUBLER (FNAL)

- ACHIEVED J_t=30,000 A/cm^2
- EMPIRICAL DESIGNS
- MINIMUM:
  - STABILITY, AC LOSSES, MOTION LOSSES, STRUCTURE, COPPER, COSTS
- 1,000 MAGNETS, 4 MILES LONG
- 40,000 LBS. NbTi
- 5,000 LITER/HOUR LIQUEFIER

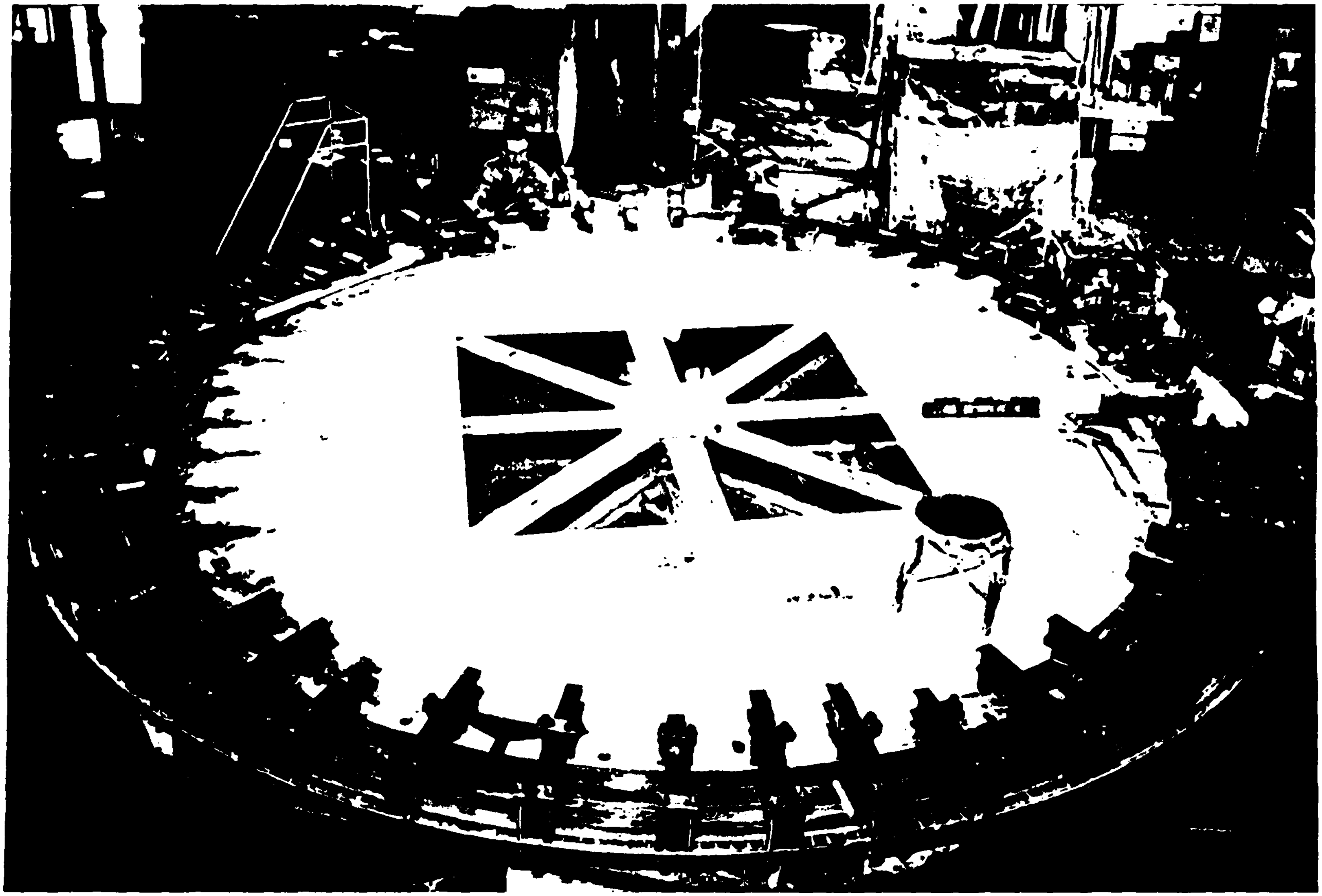
ISABELLE (BNL) SIMILAR

LEGACY

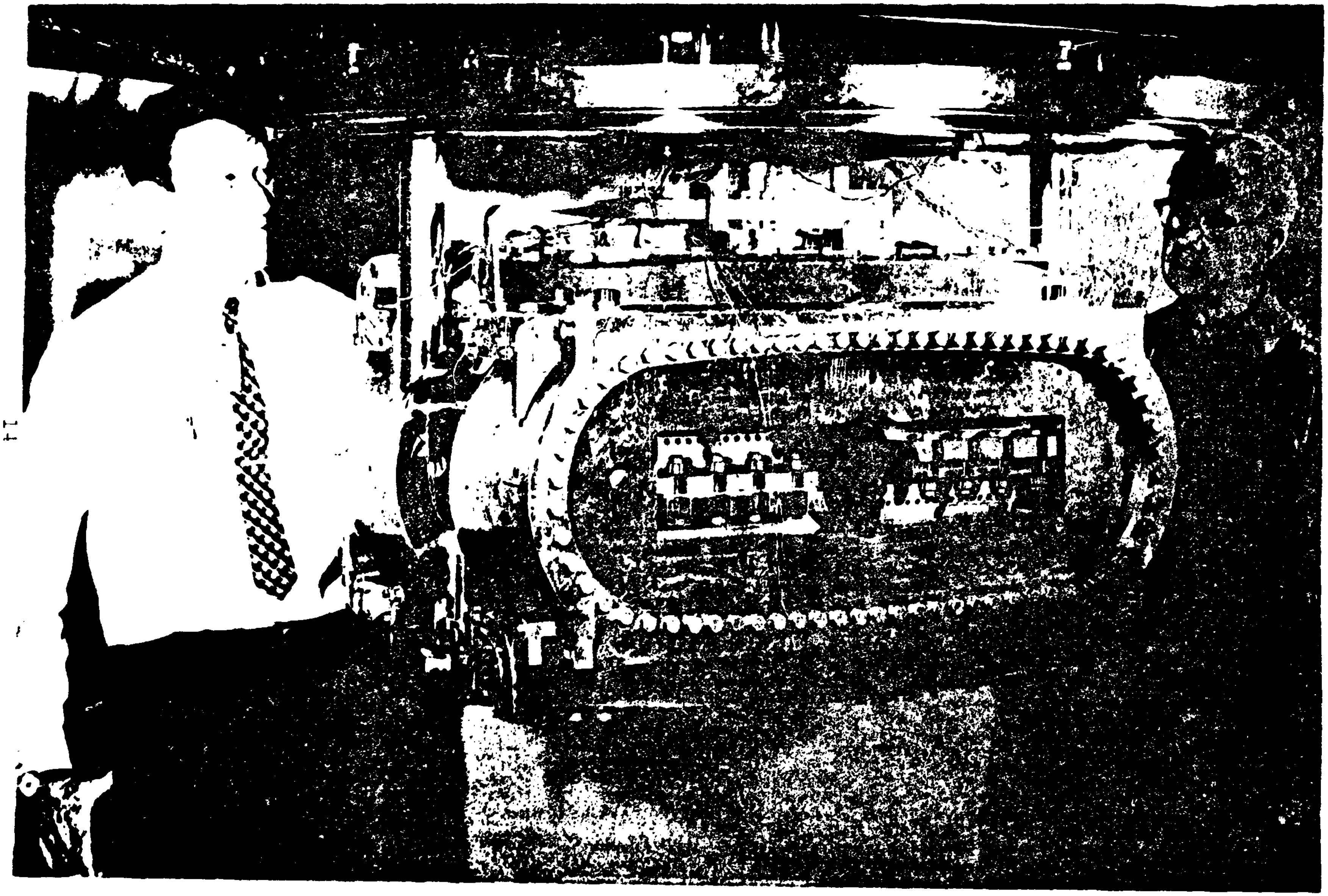
- GOOD NbTi PRODUCTION
- OVEREMPHASIS ON MARGINAL STABILITY



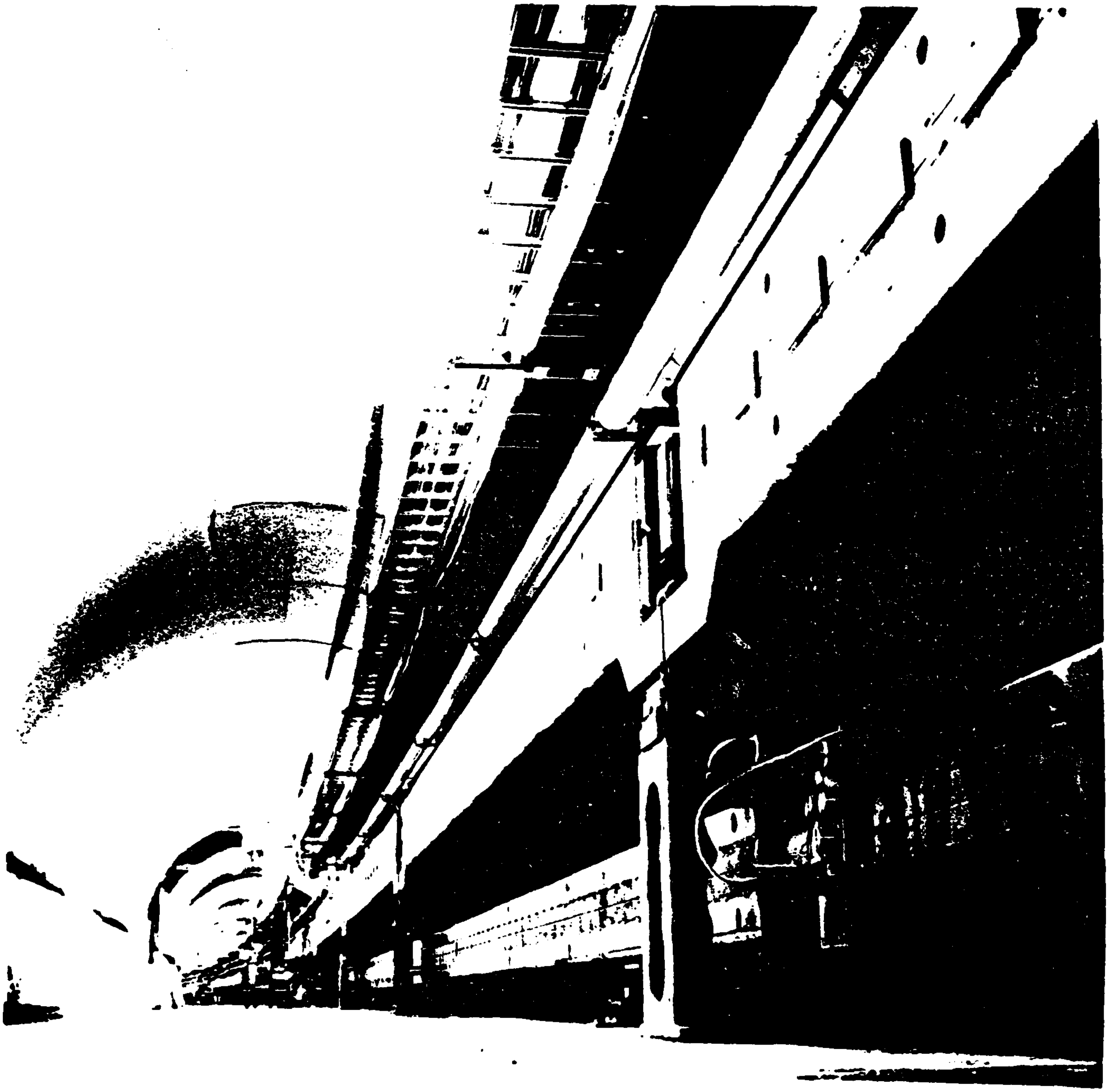
Winding the 12 ft. dia. ANL bubble chamber split solenoid in 1967.



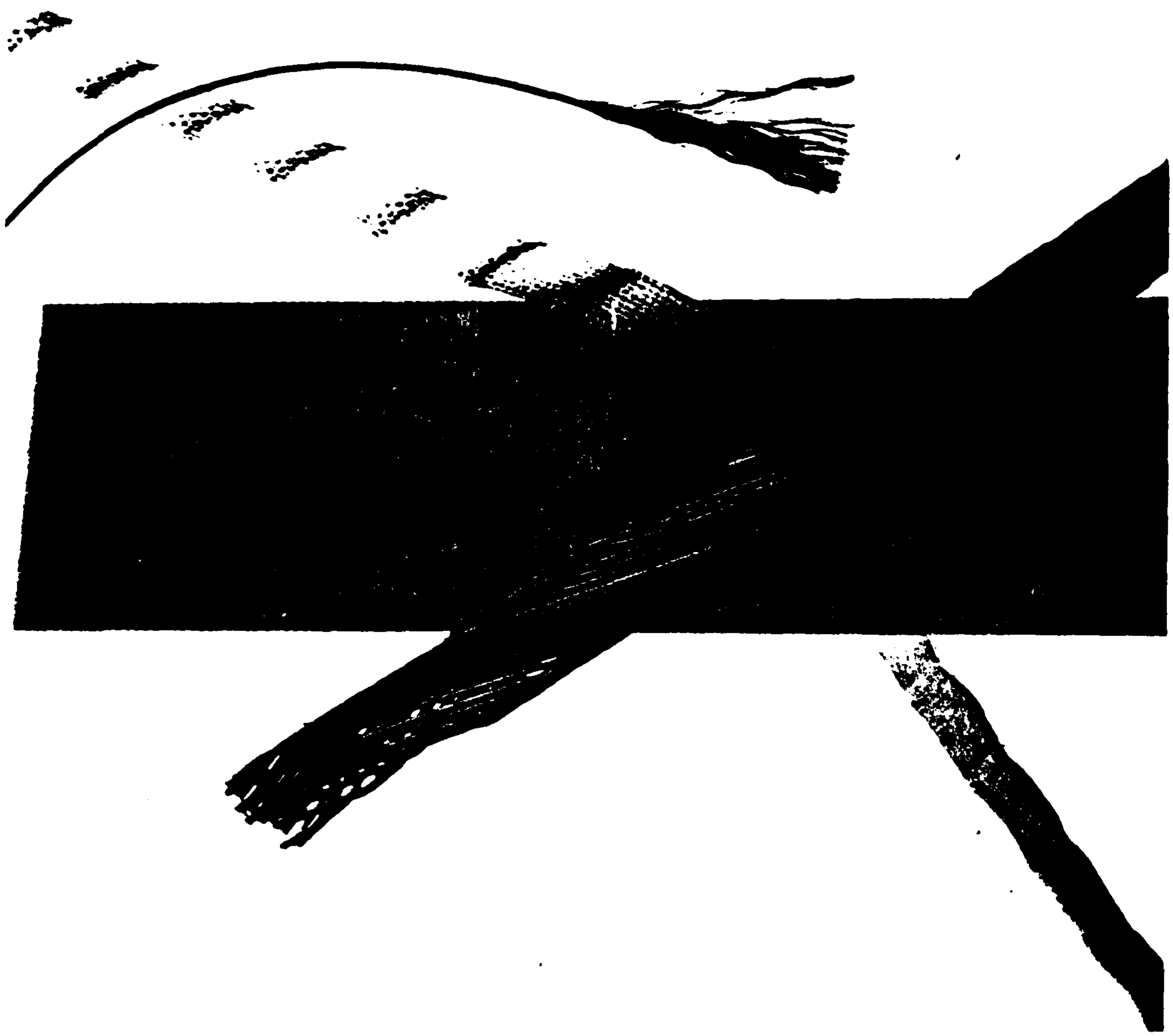
FNAL - 15 ft. dia. bubble chamber split solenoid - energy stored is
is 400 MJ. The structure is provided by the conductor.



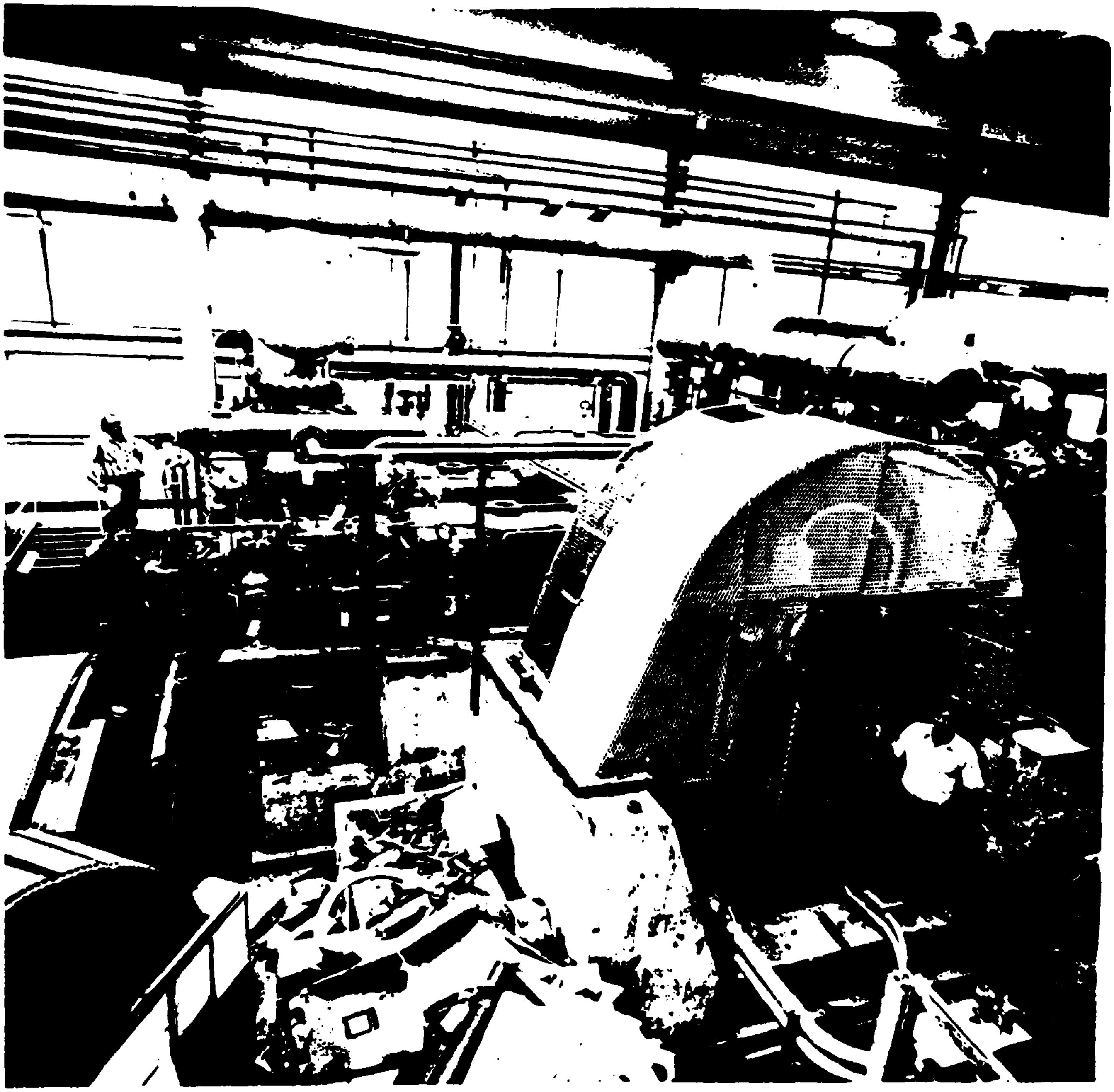
IMP - Nb_3Sn quadrupole at ORNL. Largest Nb_3Sn magnet built.



Superconductive and ordinary accelerator dipoles and quadrupoles at FNAL. There are 4 miles of NbTi accelerator magnets.



The FNAL NbTi cable. This is the first standard U.S. conductor. 23 strands, 2000 filaments 8μm per strand, operating I = 4320 A = 90% I_c, 4700 ft/magnet.



FNAL, 4000 hp compressor, two compressors provide 5000 liters of helium per hour (largest helium liquifier).

LARGE SYSTEMS

FUSION EXPERIMENTS

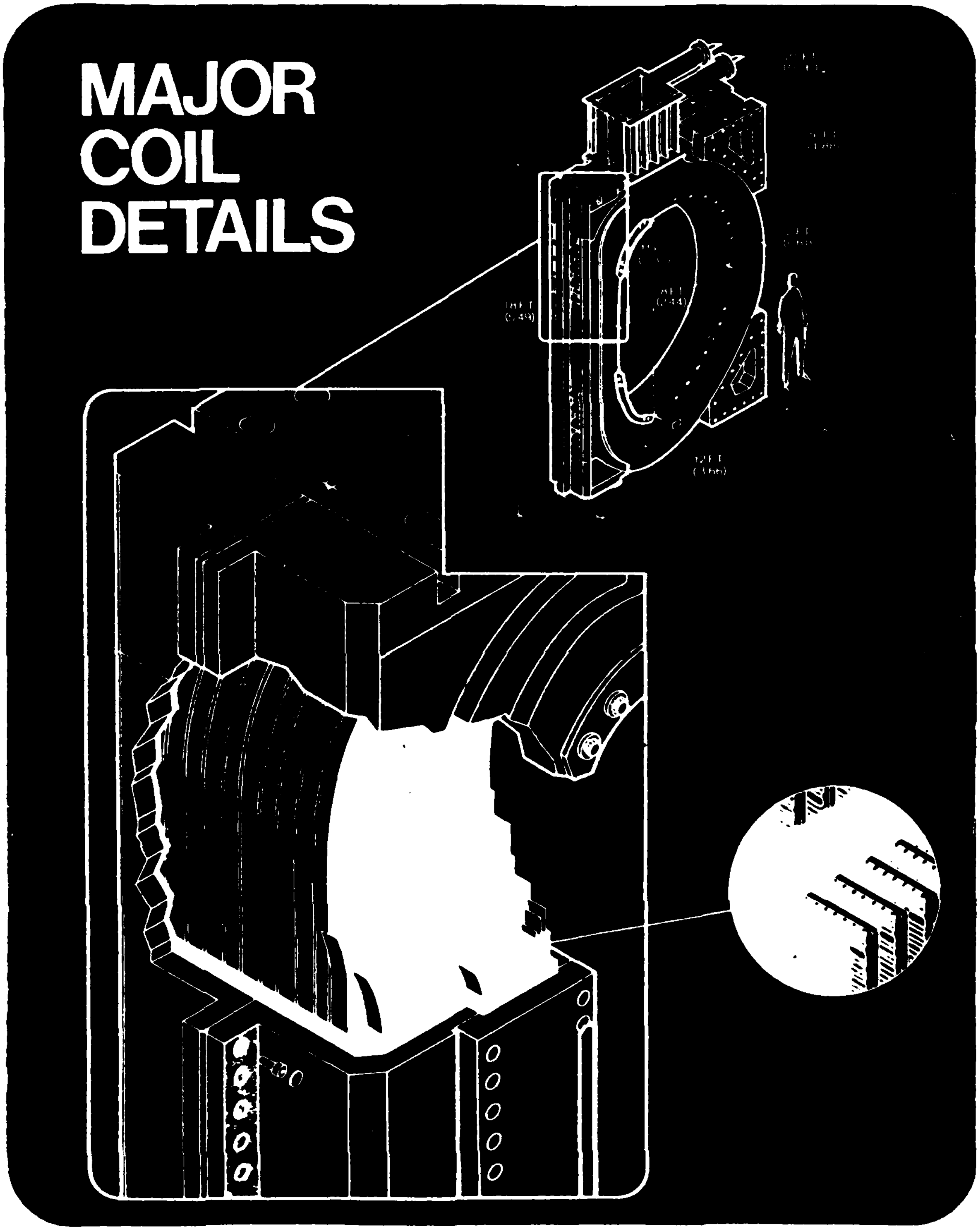
- LCP TESTED AT ORNL
- FULLY STABLE
- $\sim$2500 A/cm^2, NbTi and Nb_3Sn
- POOL COOLING AND FORCED FLOW
- NO UNCERTAINTY ABOUT "WORKING"
- MANUFACTURING AND ENGINEERING TESTS

MFTF AT LLL

- FULLY STABLE SQUARE CONDUCTOR
- CONDUCTOR FOR LATERAL COMPRESSION
- 2500 A/cm^2
- POOL COOLING, 4.5 K
- FOR PLASMA EXPERIMENTS

12 TESLA PROGRAM

- NbTi AT LOW T
- Nb_3Sn
- TESTED AT LLL



One (General Electric) of six LCP coils for test at ORNL.

MAJOR COIL CHARACTERISTICS

MAX FIELD	8 TESLA
COOLING CONCEPT	POOL-BOILING
NUMBER TURNS	668
CONDUCTOR CURRENT	10,100 AMPS
CONDUCTOR TYPE	WRAPPED SEMI-MONOLITHIC SUBELEMENTS
WINDING AREA	.273 m^2
AVERAGE CURRENT DENSITY	AMPS/cm^2 2461
WINDING CONCEPT	PANCAKE WOUND (GRADED)
WINDING SHAPE	OVAL
WINDING CROSS-SECTION	MODIFIED RECTANGULAR
CONDUCTOR REINFORCEMENT	LUMPED
STRUCTURAL MATERIAL	AISI 316LN
INTER PIE INSULATION	G-10 GROOVED SHEET
FINAL ASSEMBLY	BOLTED
TOTAL WEIGHT	392kN

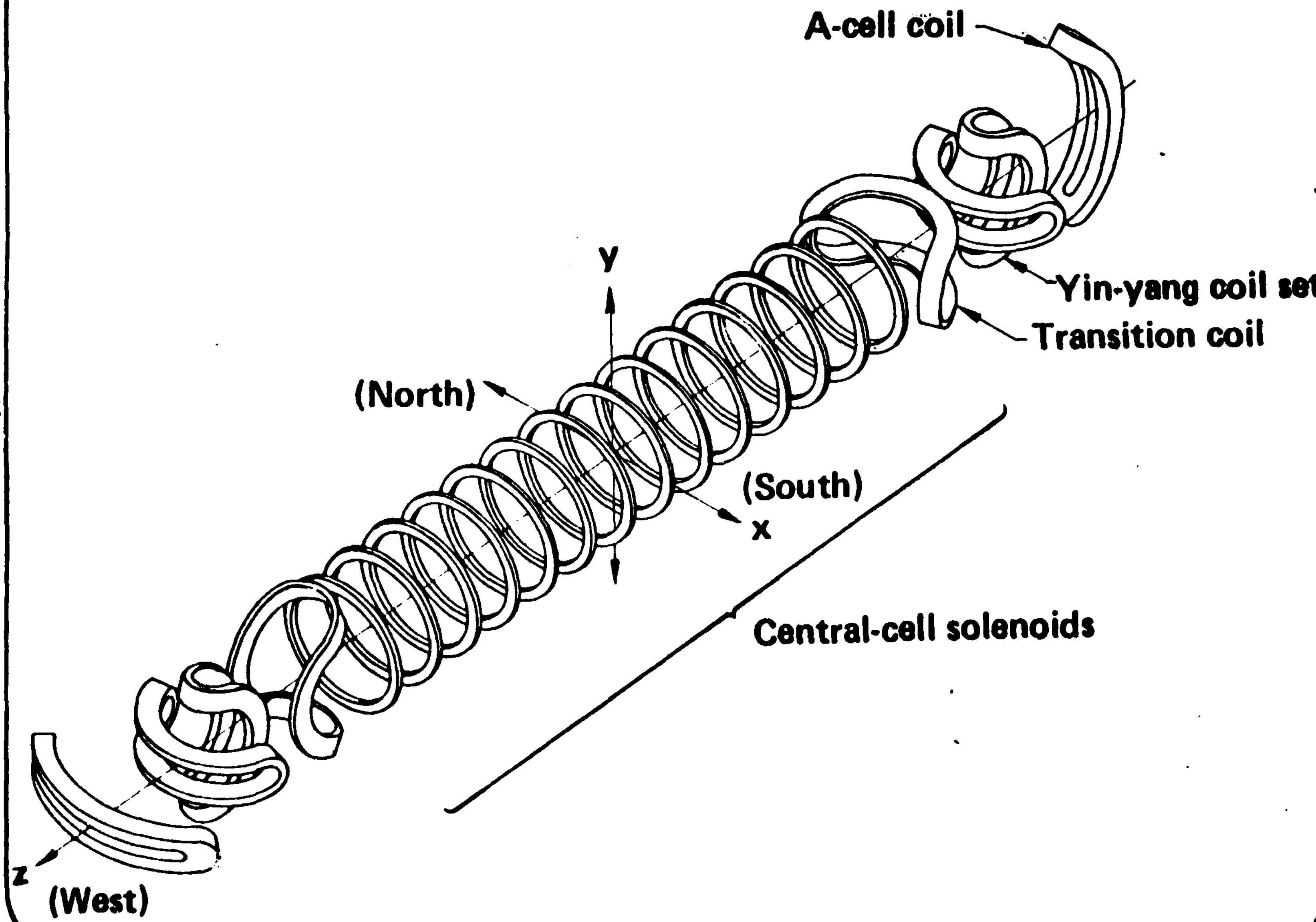
10000 AMP. FLAT WOUND, CRYOSTABLE CONDUCTOR WITH COOLING DUCTS FORMED BY SUBELEMENTS CABLED AND SOLDERED AROUND A COPPER CORE. (MADE FOR ORNL TESTS AND SIMILAR TO LCP TEST COIL CONDUCTOR.)

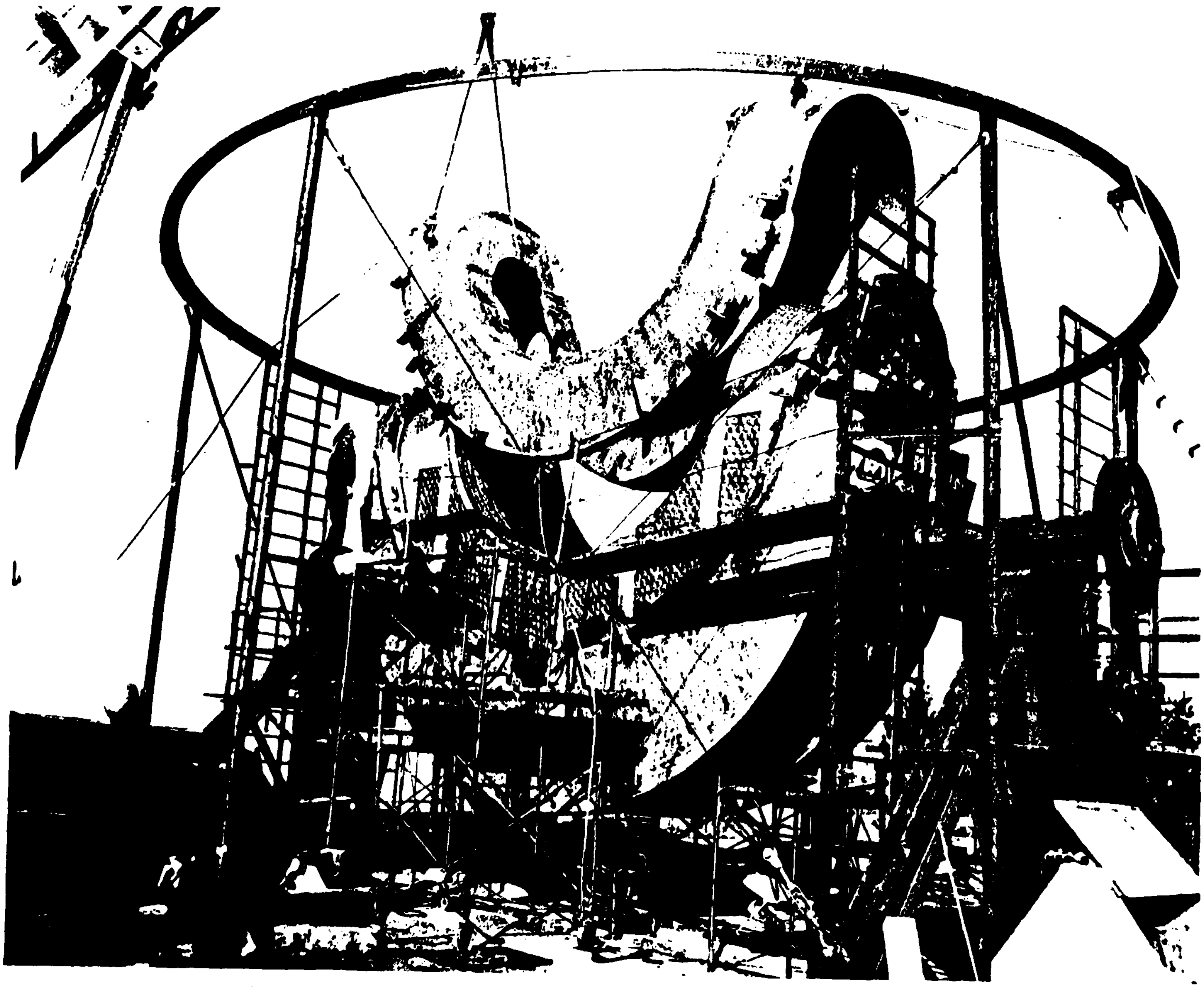
1000 AMP. SQUARE, NbTi, SUPERCONDUCTING WIRE SWAGED AND SOLDERED INTO COPPER STABILIZING SUBELEMENTS. (18 USED FOR LCP TEST COIL CONDUCTOR)

RADIATION RESISTANT, HIGH TEAR STRENGTH, SOLID, NOMEX STRIP INSULATION BETWEEN TURNS

RADIATION RESISTANT HIGH STRENGTH MACHINABLE AND FORMABLE CRYOGENIC GRADE FIBERGLASS REINFORCED EPOXY G-10 GROOVED SHEET INSULATION BETWEEN PANCAKE WINDINGS

MFTF-B MAGNET ARRAY





Ying-Yang coi[illegible] at LLL [illegible] end coils for MFTF-B, 400 M[illegible]

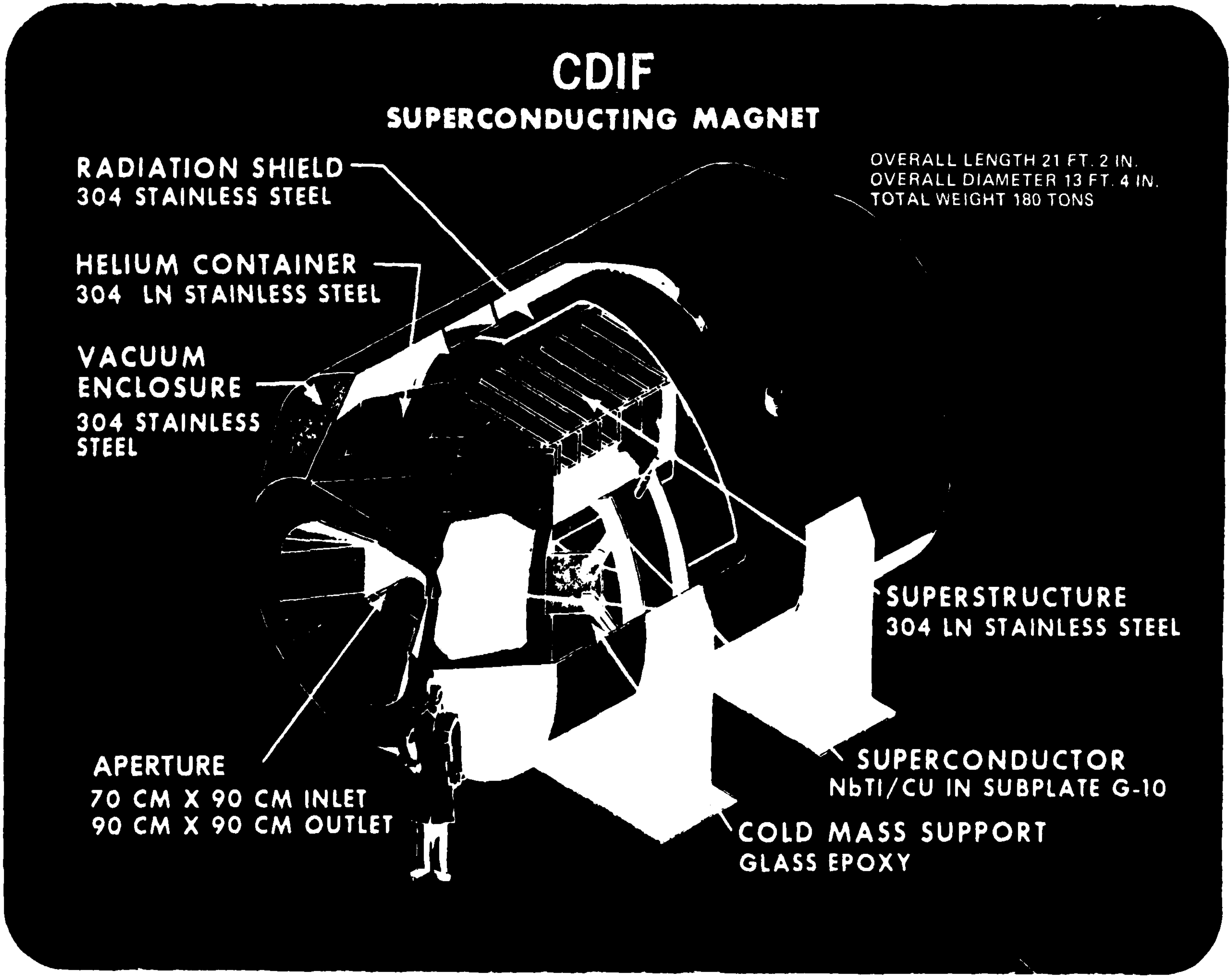
TABLE I

Magnet Parameters

On-Axis	5 Tesla (Tapered)
Winding Type	Circular Saddle w/o Iron
Orientation	Horizontal Axis
MHD Channel Apertures	40 cm dia. at Magnet Inlet 60 cm dia. at End of Effective Field
Effective MHD Channel Fields	4 T at entrance and 3.2 T at exit end
Magnetic Length	250 cm
Effective Outside Diameter	200 cm
Overall Length	440 cm
Overall Current Density	2,600 A/cm^2
Conductor Current Density	5,000 A/cm^2
Ampere Turns	6.8×10^6
Inductance	36 H
Stored Energy	20×10^6 Joules
Peak Field at Conductor	6.0 Tesla
Conductor Length at 1000 A	48,700 m
Conductor Weight	8,170 kg
Total Cold Weight	28,000 kg
Outward Force on Coils in Peak Field Region	8,900 kg/cm of Length

U-25 MHD magnet built at ANL

IL-25 under construction



CDIF - MHD sketch (G.E.).

MAJOR CHARACTERISTICS OF THE CDIF SUPERCONDUCTING MAGNET

FIELD	
PEAK ON-AXIS FIELD	6.0T
ACTIVE FIELD LENGTH	3.0m
DIMENSIONS	
OVERALL MAGNET DIMENSIONS	
DIAMETER	4.11m
LENGTH	6.45m
CENTERLINE HEIGHT	2.44m
WINDING	
AVERAGE CURRENT DENSITY ($J\lambda$)	0.18×10^8 A/m^2
AMPERE TURNS	14.22×10^6
OPERATING CURRENT	6130A
CONDUCTOR LENGTH	30800m

COOLING ENVIRONMENT	
COOLING MODE	POOL BOILING
STABILIZER HEAT FLUX	0.4 W/cm^2
ELECTRICAL	
INDUCTANCE	9.5H
STORED ENERGY	183×10^6 J
WEIGHTS	
MAGNET/CRYOSTAT ASSEMBLY	144,300kg

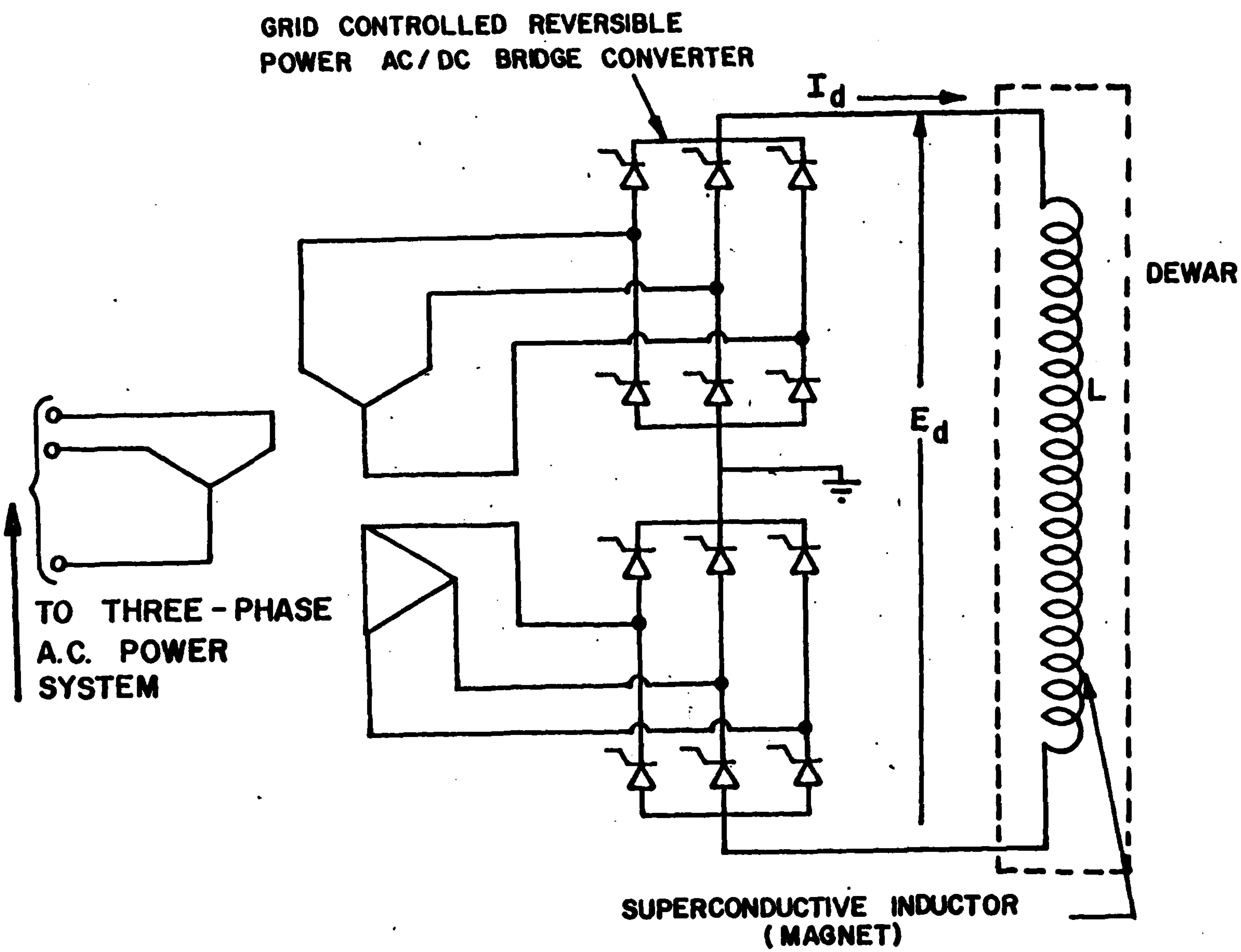
SUPERCONDUCTIVE MAGNET ENERGY STORAGE FOR ELECTRIC UTILITIES

STORES LESS EXPENSIVE ELECTRICITY AT NIGHT FOR USE THE NEXT DAY

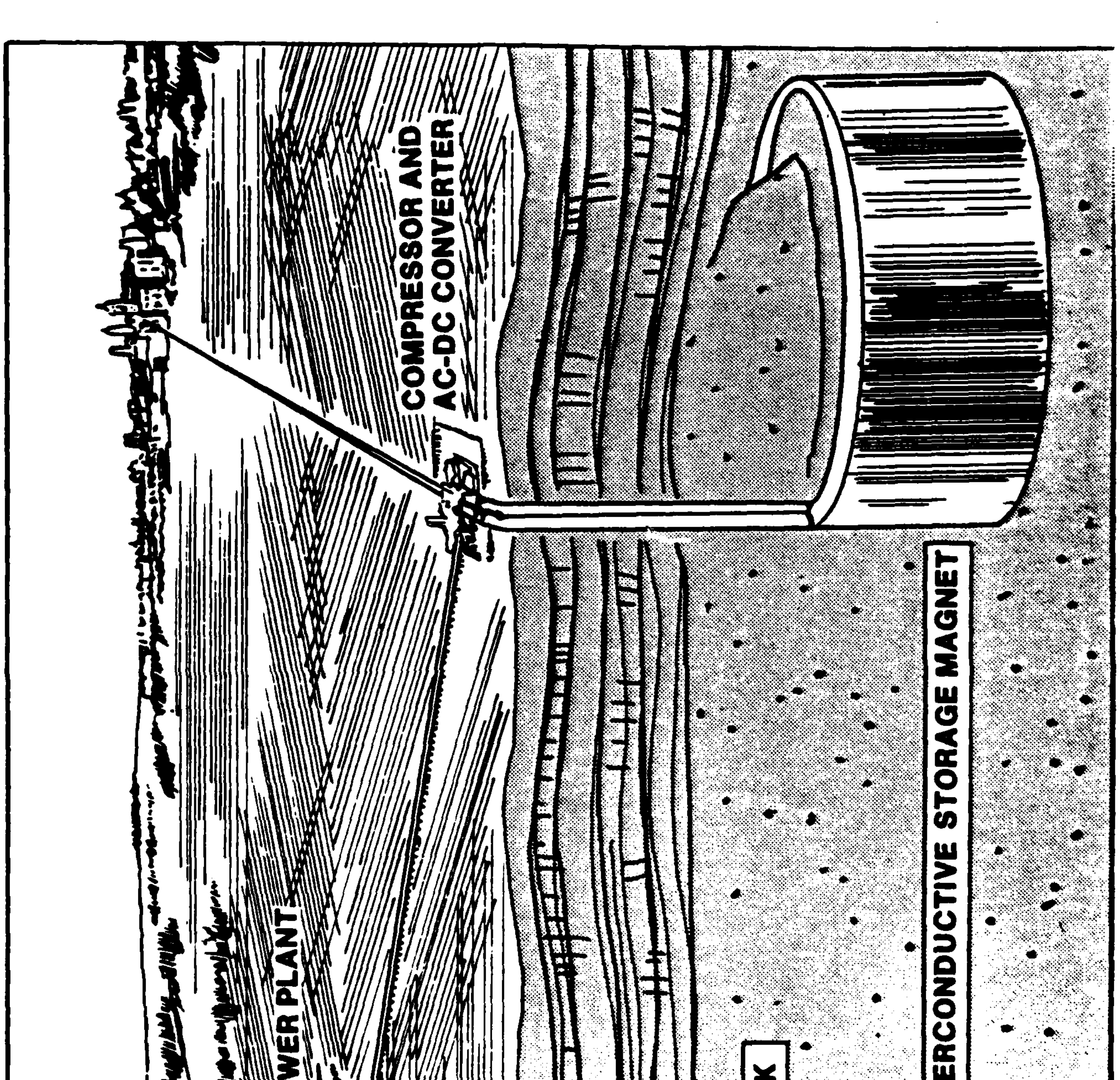
SIZE: 1,000 MWh - 10,000 MWh

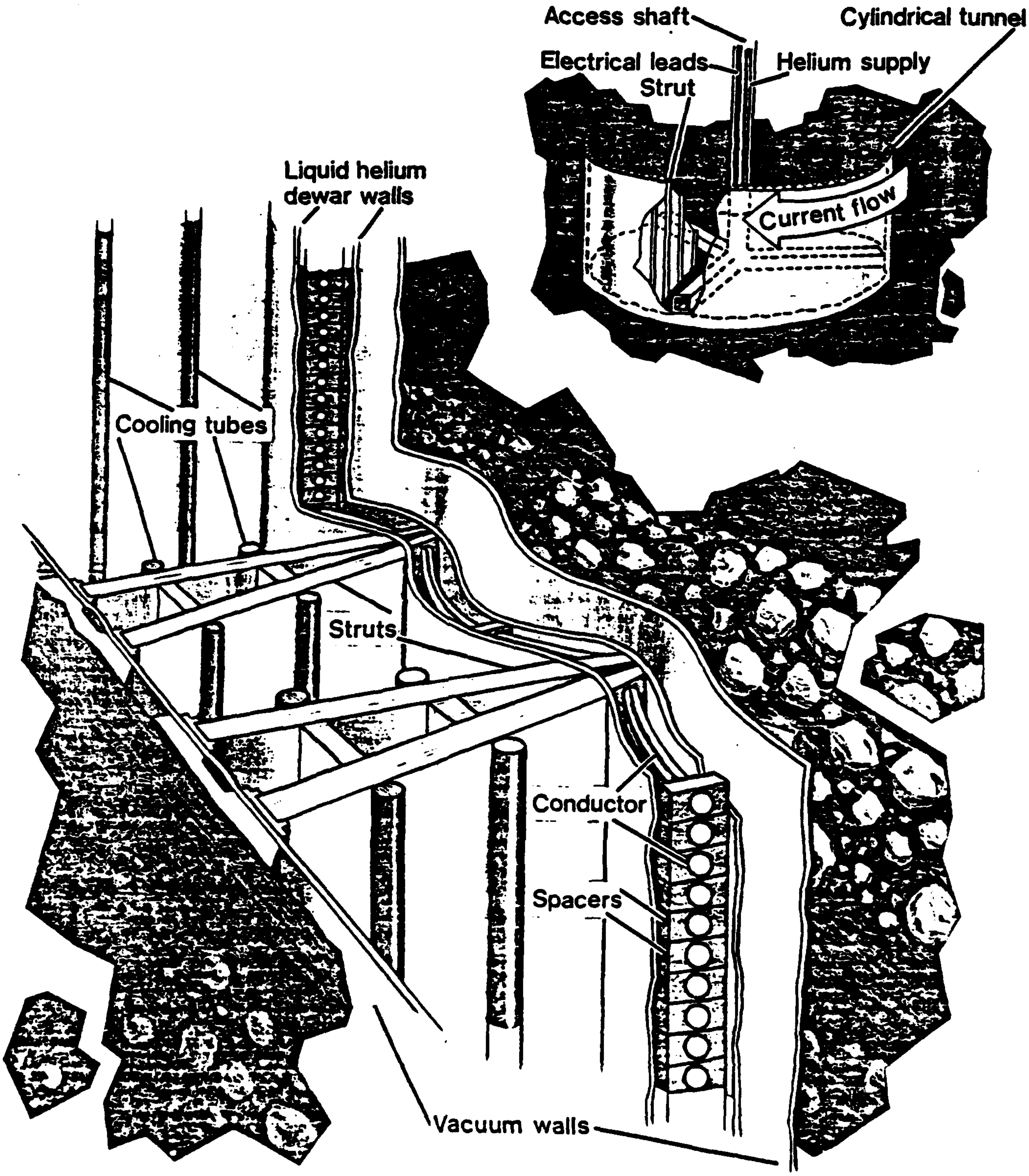
SMALL EFFORT - CONCEPTUAL DESIGN PHASE

- LARGE SIZE - 30 TO 200 m RADIUS
- BEDROCK STRUCTURE
- COST (MAIN FEATURE)
- FULLY STABLE, SUPERFLUID POOL COOLED
- NbTi PLUS Al CONDUCTOR
- 6000 A/cm^2 IN CONDUCTOR
- THIN SOLENOID- ONE LAYER
- 2.5 TO 4 TESLA
- 250,000 POUNDS NbTi FOR 1000 MWh
- 300,000 Kg HELIUM (80 MMCF - 12 DAYS)

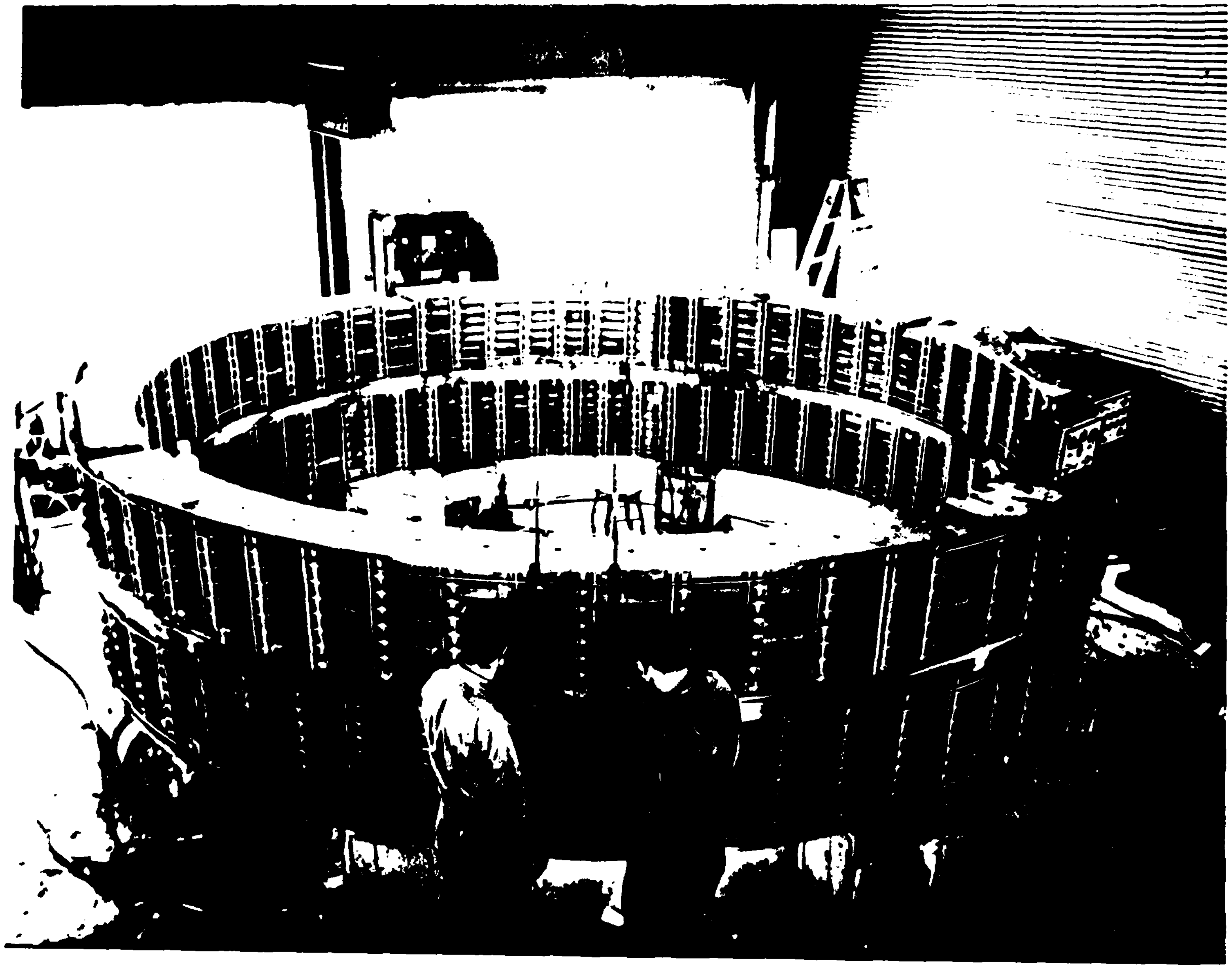


Energy storage charge - discharge 3-phase bridge, efficiency ~ 95%.

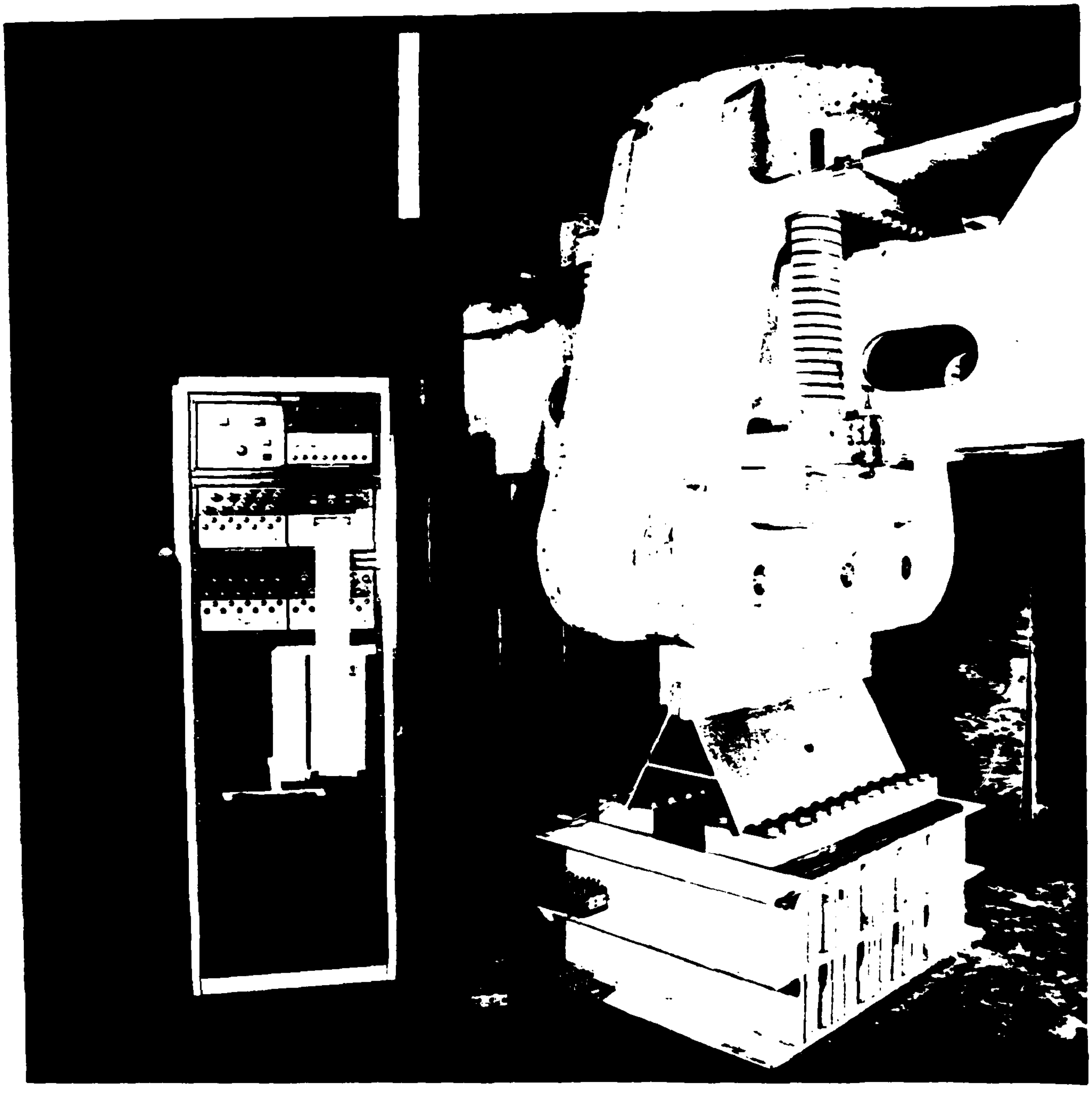

POWER PLANT
COMPRESSOR AND
AC-DC CONVERTER
BEDROCK
SUPERCONDUCTIVE STORAGE MAGNET



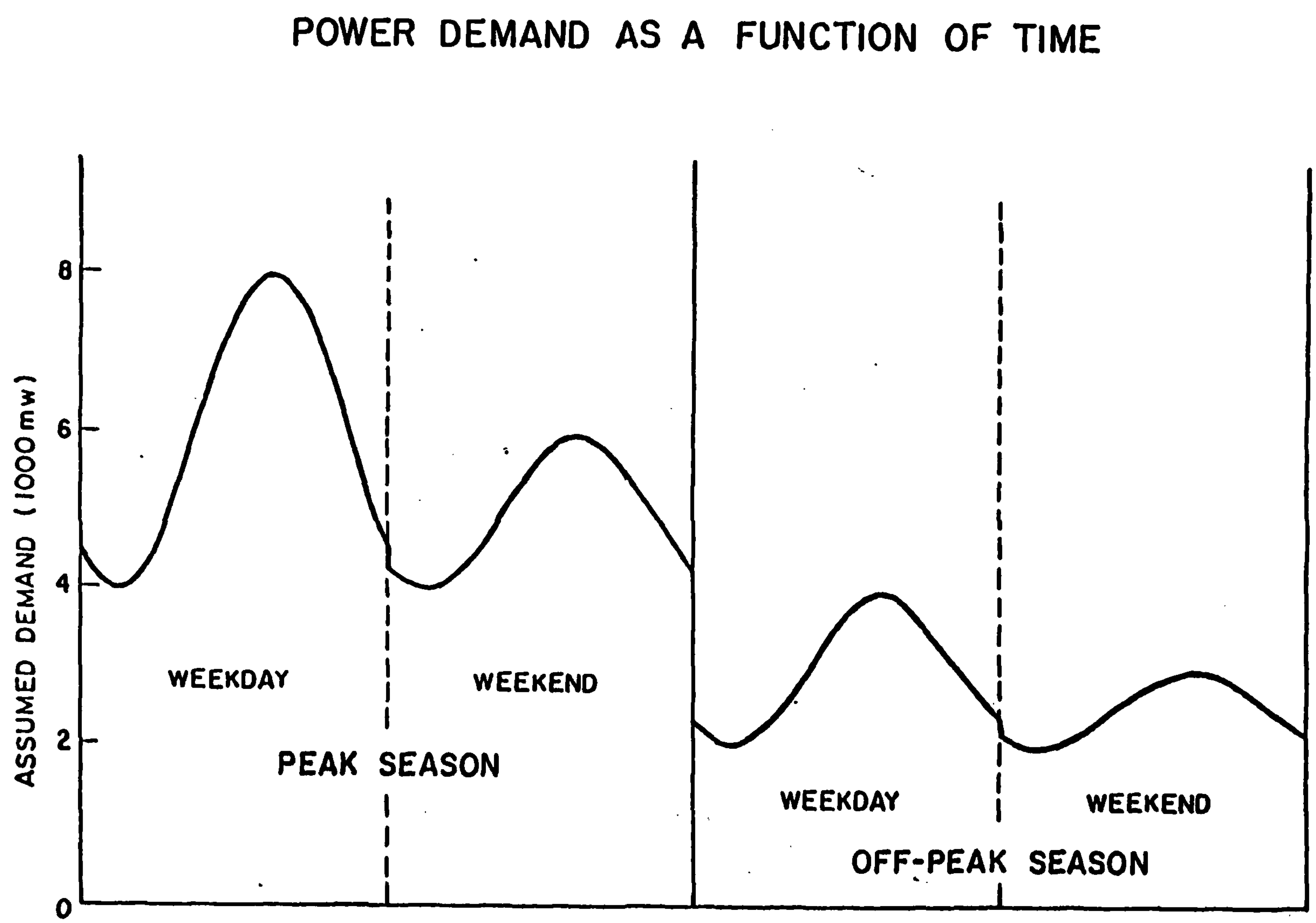
Storage solenoid cut-away.



Storage conductor under development.



Storage strut tests.



A.D. Little storage study.

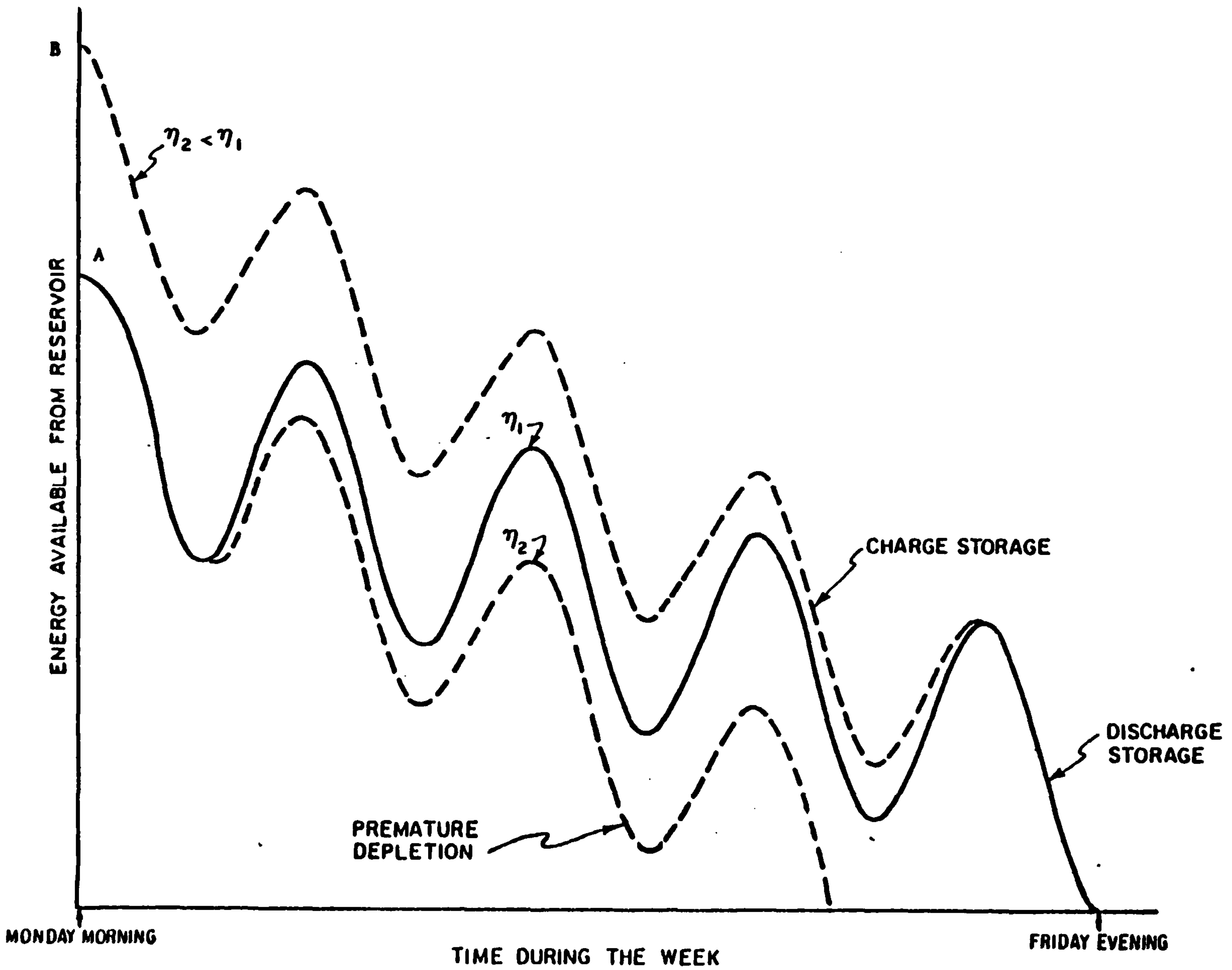


FIGURE 3.2 ENERGY IN RESERVOIR AS A FUNCTION OF TIME DURING THE WEEK FOR TWO STORAGE SYSTEMS WITH DIFFERENT CYCLE EFFICIENCIES - EQUAL ENERGY TO THE LOAD.

UPH - UNDERGROUND PUMPED HYDROSTORAGE
CAES - COMPRESSED AIR STORAGE
Pb/H^{+} AND ADV - BATTERY STORAGE
SMES - SUPERCONDUCTIVE MAGNET ENERGY STORAGE

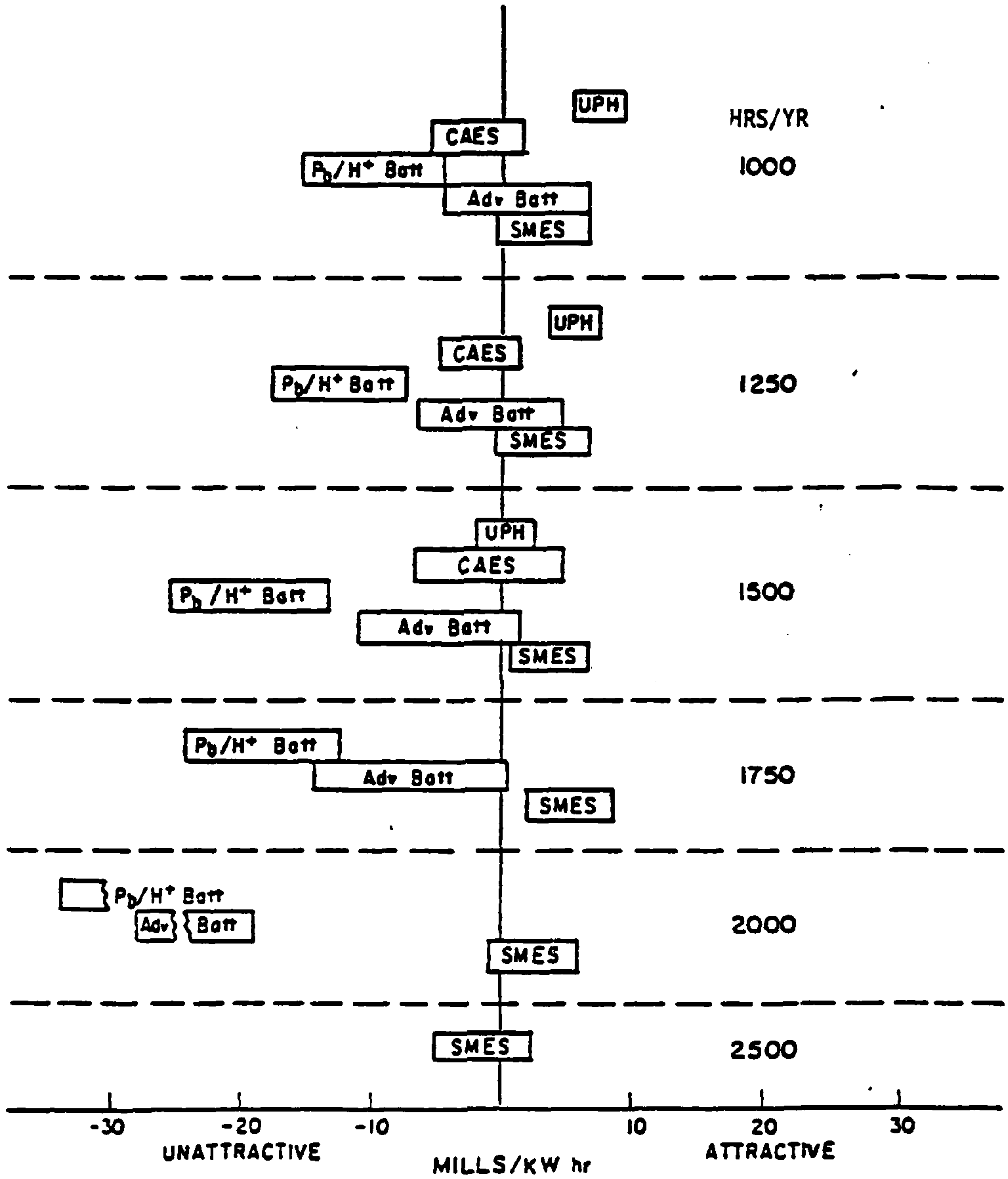


FIGURE 3.6 LEVELIZED BUS BAR COST DIFFERENCE BETWEEN STORAGE AND CONVENTIONAL GENERATION C=15 Mills/kw hr. P_d (max) = 1000 MW

(A.D. Little, Inc.)

Comparison of SMES with other storage systems.

CONCLUSIONS

SMES CAN COMPETE ECONOMICALLY WITH THE ALTERNATIVES FOR ALL SCENARIOS CONSIDERED

THE KEY ISSUE IS THE PROPER SIZING OF THE STORAGE SYSTEMS TO MEET THE NEEDS OF THE UTILITY

SMES CAN BE USED BY UTILITIES WHICH CANNOT ECONOMICALLY USE ANY OTHER TYPE OF STORAGE SYSTEM

ITS HIGH CYCLE EFFICIENCY AND FAST RESPONSE TIME ALSO ALLOWS SMES TO BE USED TO IMPROVE SYSTEM EFFICIENCY DURING PERIODS WHEN THE LOAD IS CHANGING

(A.D. Little, Inc. April 2, 1979)

PRESENT TRENDS

CONDUCTOR MOUNTING

COPPER + Nb_3Sn COMPOSITES

SUPERFLUID COOLING

H_{c_2} INCREASE FOR NbTiTa

NB_3SN

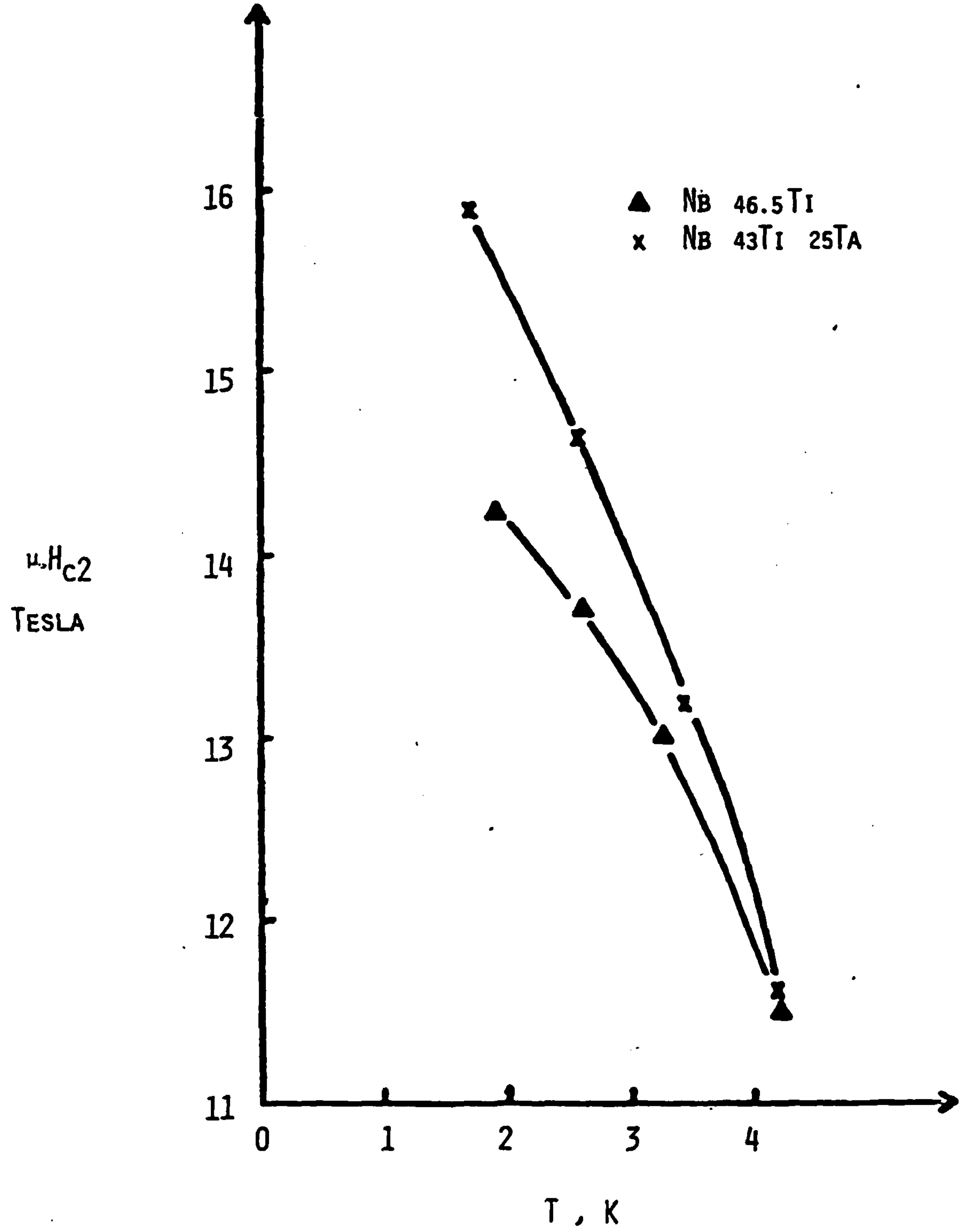
BRITTLE BUT ENGINEERING MATERIAL

ACCEPTABLE IN FILAMENTARY FORM

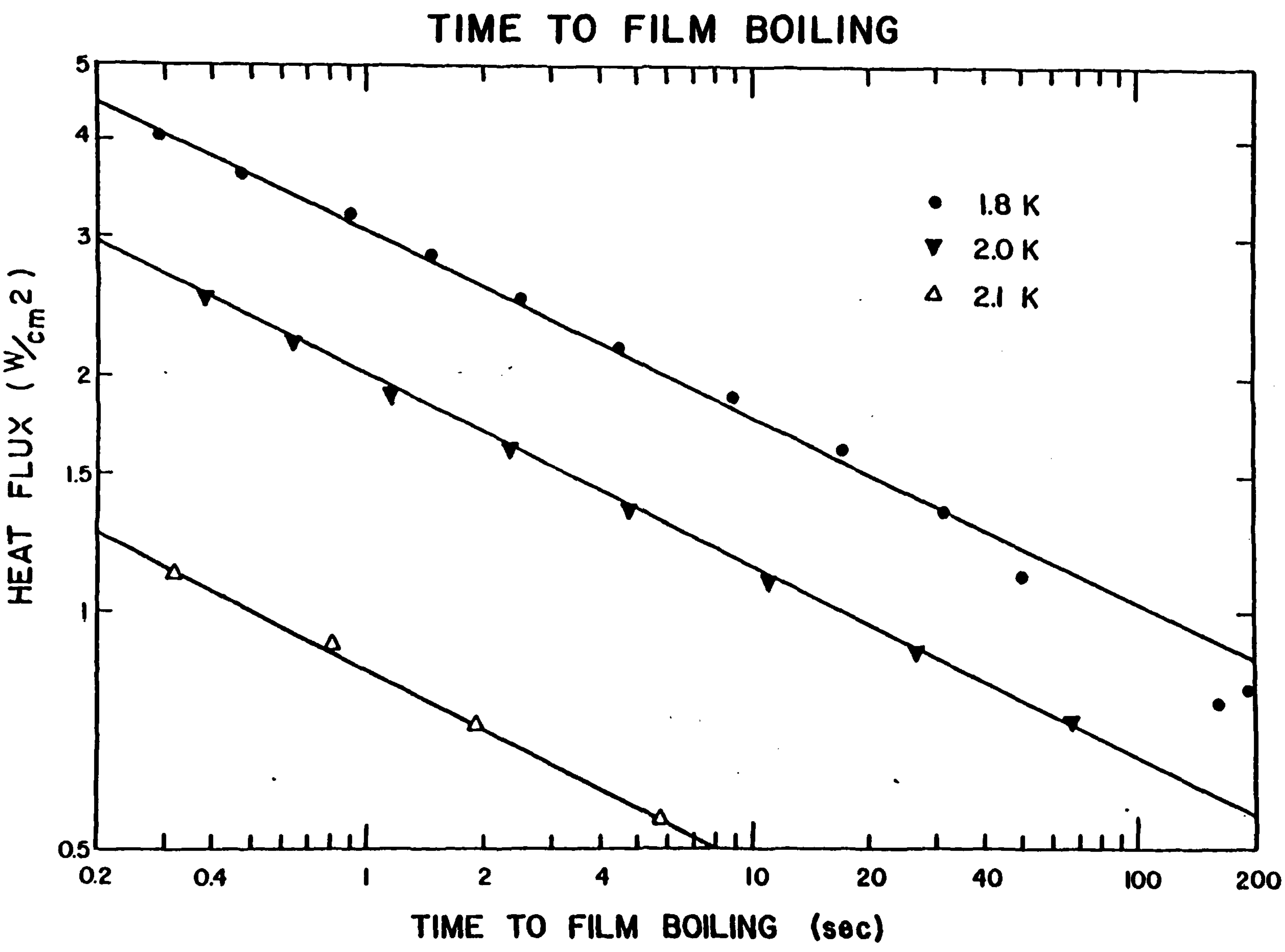
- FINE FILAMENTS FAIL AT LARGER STRAINS
- BRONZE COMPRESSES Nb_3Sn

RESULT: FAILURE STRAINS OF $\sim$ 1% RATHER THAN 0.2%

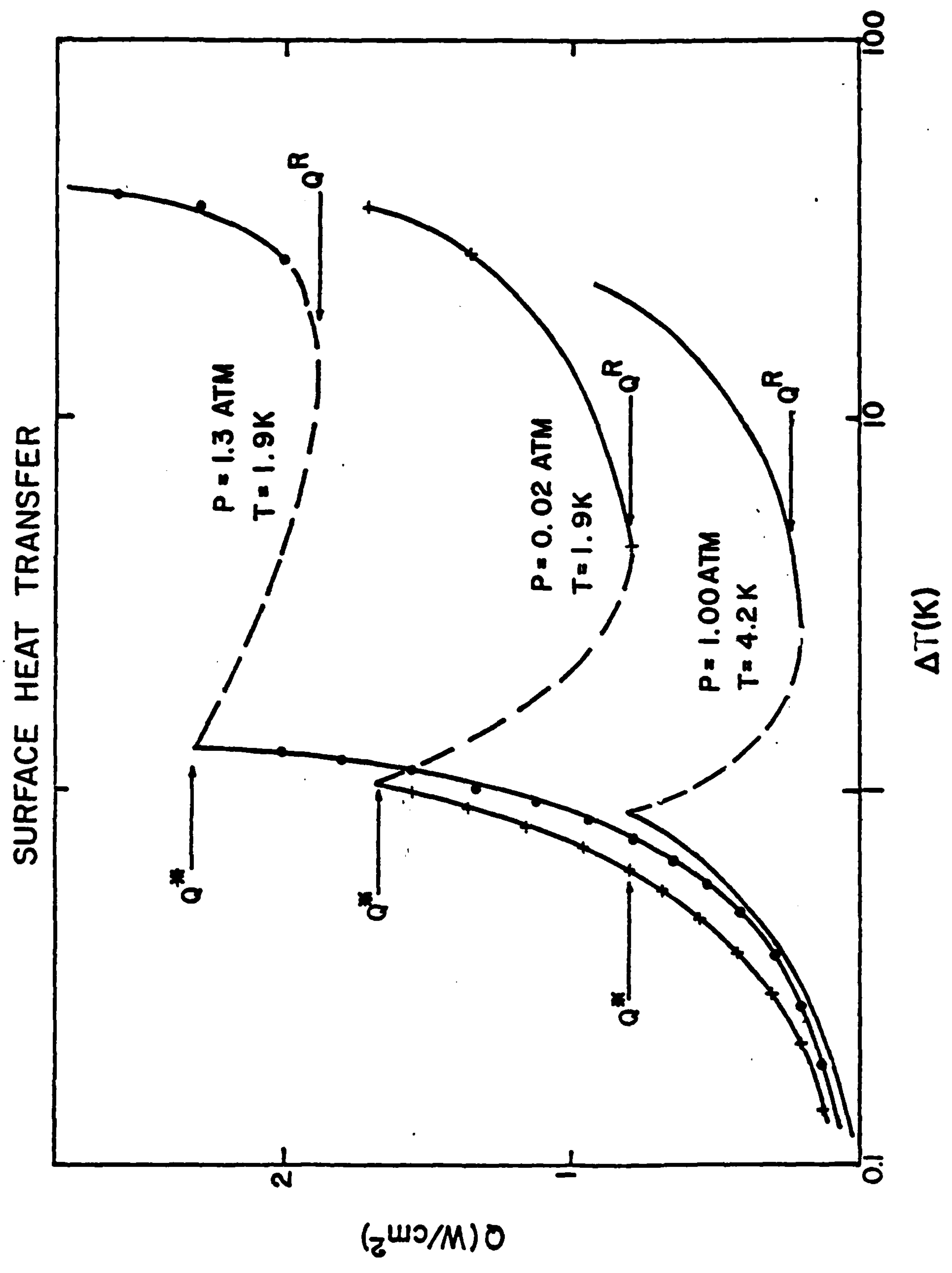
NEEDS: PRODUCTION VOLUME AND MAGNET EXPERIENCE



Low temperature, higher H_{c_2} due to Ta addition, (Wisconsin).



Superfluid heat transfer tests (Wisconsin).


SURFACE HEAT TRANSFER
P = 1.3 ATM
T = 1.9K
P = 0.02 ATM
T = 1.9K
P = 1.00 ATM
T = 4.2K
Q*
Q*
Q*
Q^R
Q^R
Q^R
Q(W/cm²)
2
1
0.1
10
100
ΔT(K)

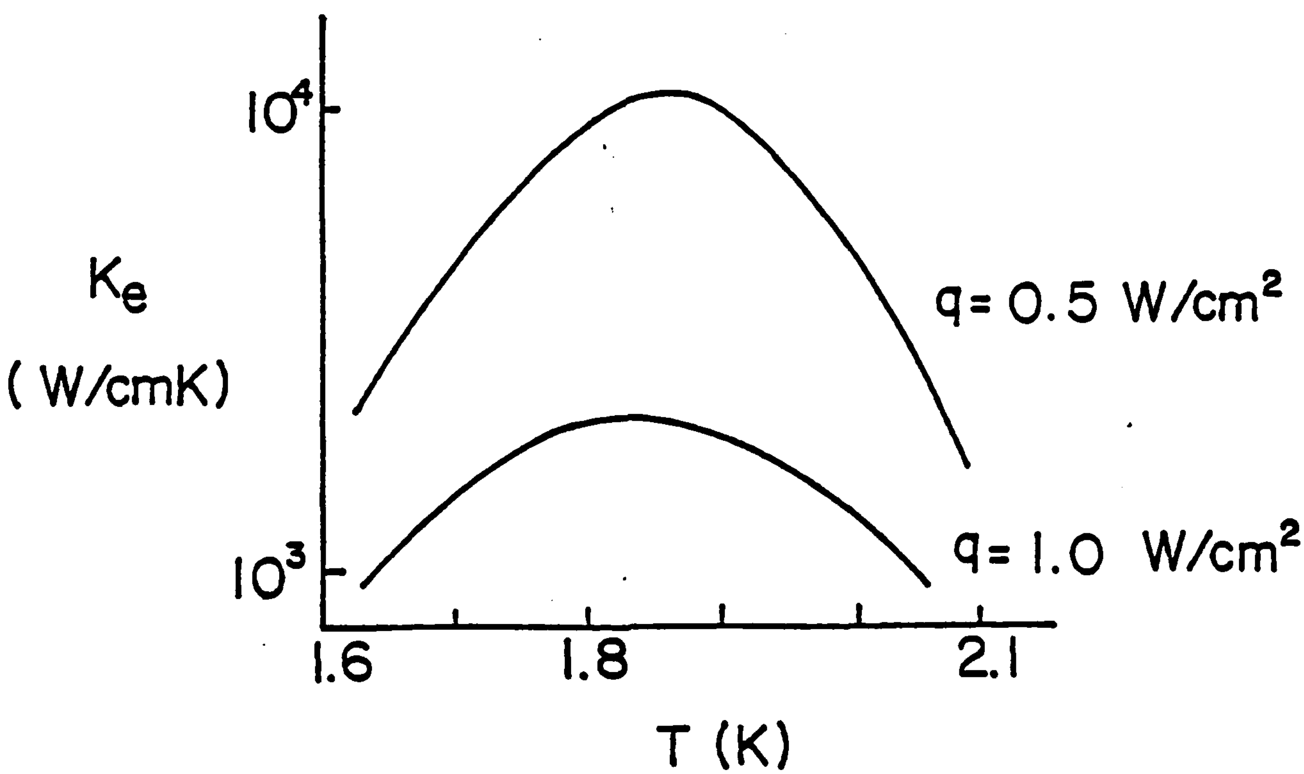
HEAT TRANSPORT IN He II

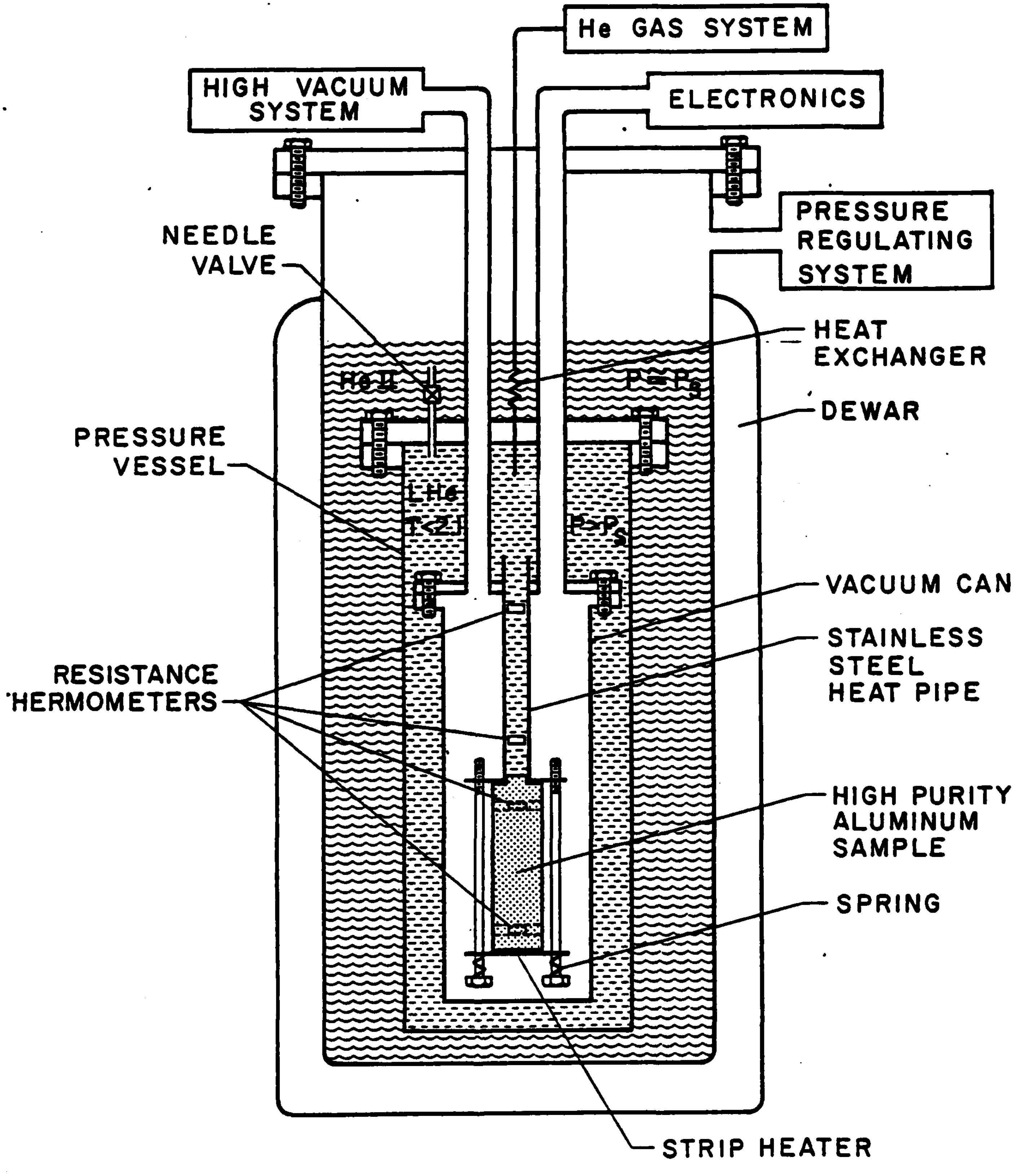
CONDUCTION EQUATION:

$$\frac{dT}{dx} = f(p,T)\,q^3$$

EFFECTIVE THERMAL CONDUCTIVITY

$$K_e \equiv \frac{1}{f(p,T)\,q^2}$$





Pulsed heaters in He II.

AC COILS

HYSTERESIS

FNAL - $\Delta E/\text{cycle} \propto B_{MAX}$

0.2 T/SEC TO 4T @ 400 J/CYCLE

EDDY CURRENT LOSS

ANL - FULLY STABLE CABLE SOLENOID

9 T/SEC TO 4.5 T @ 2500 A/CM^2

$$\frac{\Delta E}{E} = \left(\frac{\Delta E}{E_o}\right) \left(\frac{T_o}{T}\right) = 10^{-3} \left(\frac{T_o}{T}\right)$$

AT RISE TIME $\quad T = 0.5$ SEC

CABLE HEAT FLUX $Q = 0.01$ W/CM^2

EXTRAPOLATE $\quad QT =$ CONSTANT

CONCLUSION

DESIGN OPTION - STABILITY VS. REFRIGERATION

PREDICTIONS FOR LARGER SYSTEMS

CONDUCTOR

$J_t \sim \frac{\sigma}{BR}$, DECREASE WITH SIZE

MORE SPACE FOR EXTRA STABILITY

MORE COPPER, COOLING, HELIUM

MORE INTEREST IN SUPERFLUID HELIUM

LESS INTEREST IN MARGINAL STABILITY

FIELDS

OPTIMIZATION PROBABLY TOWARDS LOWER FIELDS AT LARGER VOLUMES

PREDICTIONS FOR LARGER SYSTEMS

STRUCTURE

EASIER DESIGNS IN MORE SPACE

VIRIAL THEOREM - STRUCTURAL MASS

$M_T - M_C > \rho/\sigma \; E$ (UNIDIRECTIONAL)

M_T = MASS IN TENSION

M_C = MASS IN COMPRESSION

ρ = DENSITY

σ = AVERAGE STRESS

$$E = \int_V \frac{B^2}{2\mu_0} dv = \text{STORED ENERGY}$$

SAFETY

ORDINARY OPERATION - SAFER BECAUSE OF EXTRA STABILITY MARGINS

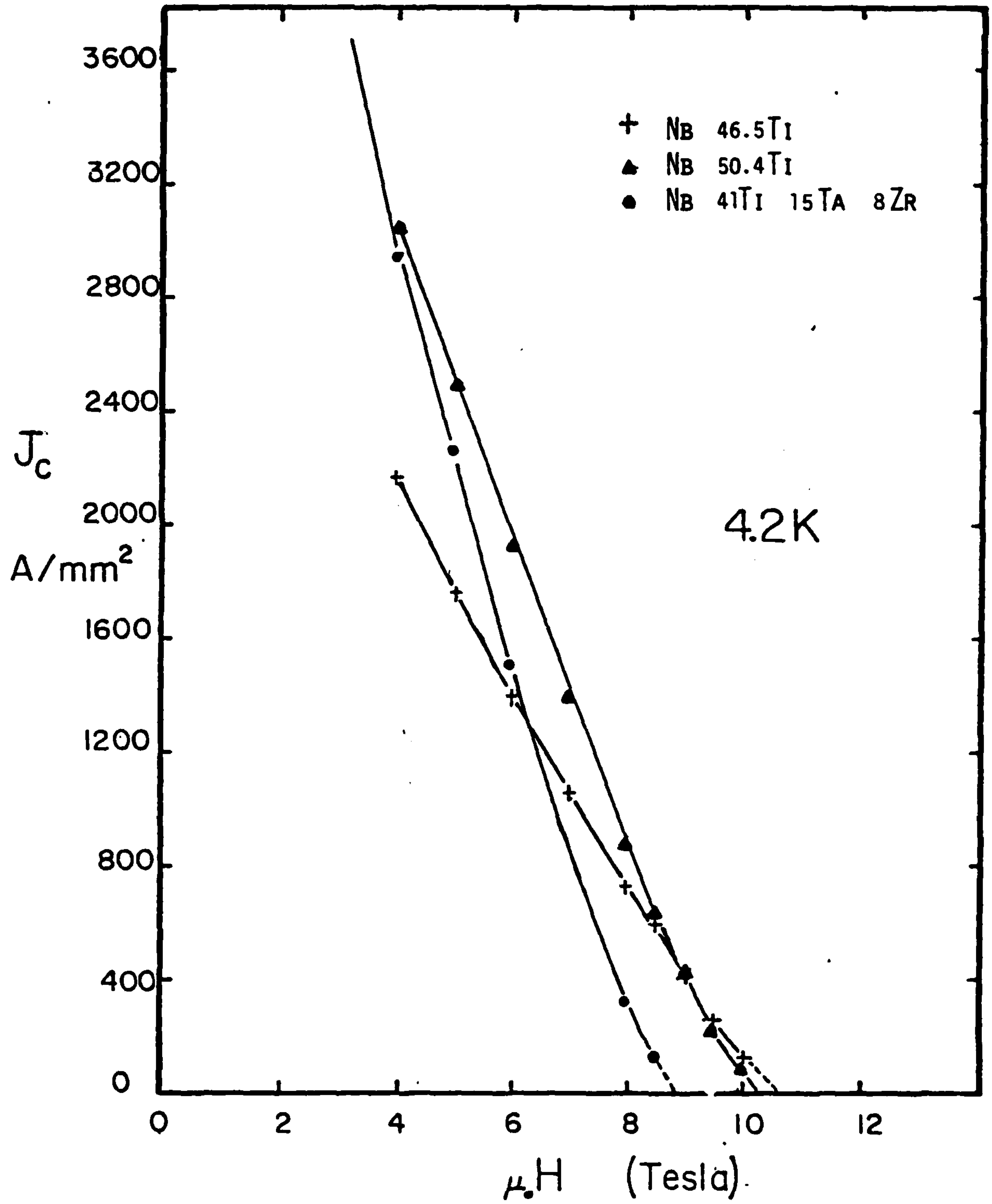
CATASTROPHIC OPERATION - TO 300 K AND ABOVE - REDUCED SAFETY DUE TO BETTER EFFICIENCY PER AMPERE-METER

$$\frac{\text{ENERGY}}{\text{AMP METER}} \propto BR$$

CONSEQUENCES: MORE STRINGENT SAFETY, ESPECIALLY FOR COMMERCIAL UNITS

FUTURE GOALS

- NbTi & Nb_3Sn IMPROVEMENTS
- LESS Nb (COST)
- HIGHER J_c (LESS SUPERCONDUCTOR)
- HIGHER T_c
- ALUMINUM STABILIZER (1/7 vs. Cu)



Higher J_c - Low B conductors.
+FNAL (U.S.), ▵ Vacuumschmelze (W. Germany)
·Kobe Steel (Japan)

MAJOR NEEDS

BETTER RESEARCH COMMITMENT

BETTER FINANCING FOR CONDUCTOR MANUFACTURERS

IRD OR INCENTIVE

GOVERNMENT SEMI-CAPTIVE INDUSTRY

SUPERCONDUCTIVITY ACTIVITIES AT LASL*

Presented by William E. Keller
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

ABSTRACT

We briefly survey the LASL superconducting programs in materials and physics research on superconductors--eg., A-15 compounds, magnetic/reentrant superconductors, electron-phonon interaction, intermetallic compounds, superconductivity dynamics--and on applications--e.g., energy storage, tokamak induction heating, VAR control, power transmission lines, SQUIDS. As an example of recent progress, we cite a study of ac losses in Nb_3Ge tapes, showing how the total losses in these tapes can be restricted to hysteretic losses.

*Work conducted under the auspices of the U.S. Department of Energy

SUPERCONDUCTIVITY
AT LASL

MATERIALS RESEARCH - CMB DIVISION

GIORGI, SZKLARZ, NEWKIRK
SMITH, STEWART, WILLIS (MATTHIAS)

PHYSICS RESEARCH/DEVICES - GROUP P-10

HUANG, TAYLOR, MALEY, THOMPSON,
OVERTON, CARLSON, BARTLETT

MAGNET DEVELOPMENT/APPLICATIONS - GROUP CTR-9

ROGERS, SCHERMER, WOLLAN, THULLEN,
BOENIG, CHOWDHURI

MATERIALS AND PHYSICS RESEARCH

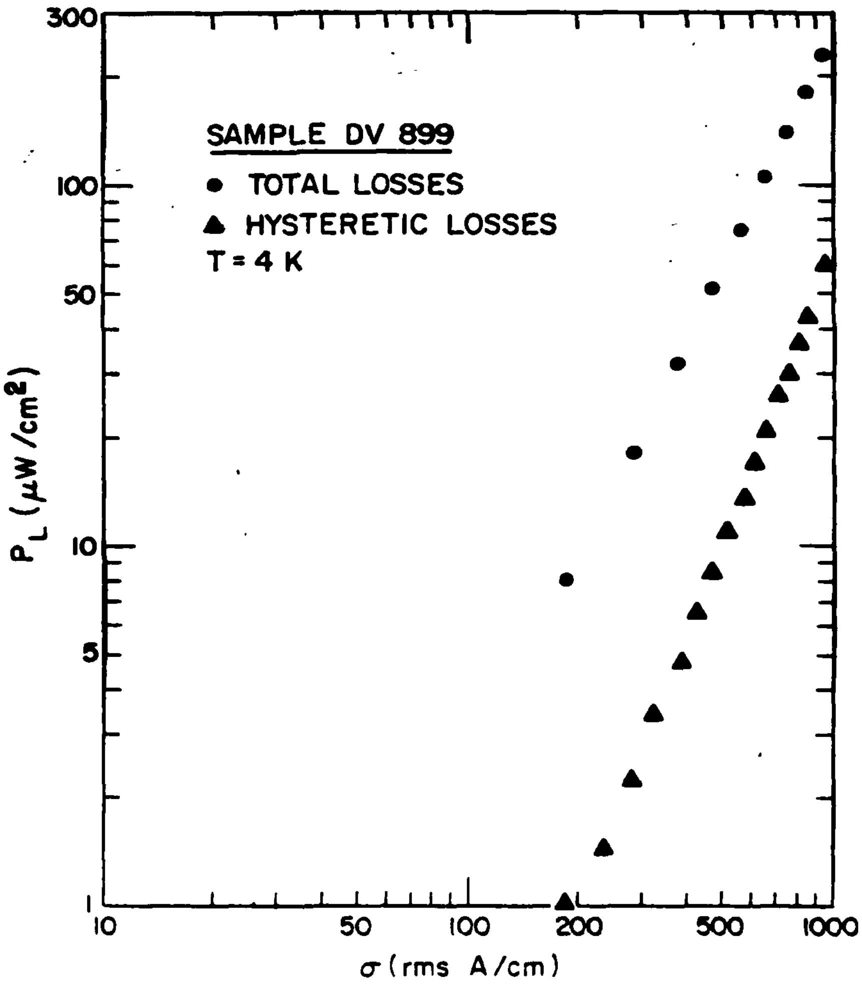
	SPONSOR
A-15 COMPOUNDS	
HEAT CAPACITY - N(O)	LASL
Nb_3Ge-CVD - THIRD ELEMENT	DOE/EES
Nb_3Si - HIGH P	LASL
MAGNETIC/REENTRANT SUPERCONDUCTORS	LASL
$Sn_{1-x}Eu_xMo_6S_8$ - HIGH FIELD SC ?	
R_H, $\rho(T)$, M, HIGH P, HIGH H/T, MOSSBAUER EFFECT	
$ERRh_4B_4$, $ERRh_{1.1}Sn_{3.6}$ -TYPE I ?	
λ, H_{C2}, HIGH P, μSR	
ELECTRON-PHONON INTERACTION	LASL
Zr-Zn SYSTEM } ITINERANT FM	
Ti-Be-Cu SYSTEM } +SC ?	
T_c ENHANCEMENT AT EUTECTIC	LASL
Y-Ir SYSTEM	
Tc INTERMETALLIC COMPOUNDS	LASL
LAVES PHASES WITH Sc, Y, Lu	
SC DYNAMICS	LASL
ASSYMETRIC NORMAL ZONE PROPAGATION	
HELICAL CURRENTS	

APPLICATIONS/HARDWARE DEVELOPMENT

	SPONSOR
TOKAMAK INDUCTION HEATING	DOE/OFE
MAGNETIC ENERGY STORAGE	DOE
METS	OFE
BPA STABILIZER	ESS-EES
LOAD LEVELING	ESS
VAR CONTROL	EES
HIGH-V, HIGH-I SWITCHING	OFE
TRANSMISSION LINES - SPTL	
SUPPORT FOR BNL	DOE/EES
Nb_3Ge AC CABLE	EPRI
SQUID FOR GEOSCIENCES	DOE/GEP

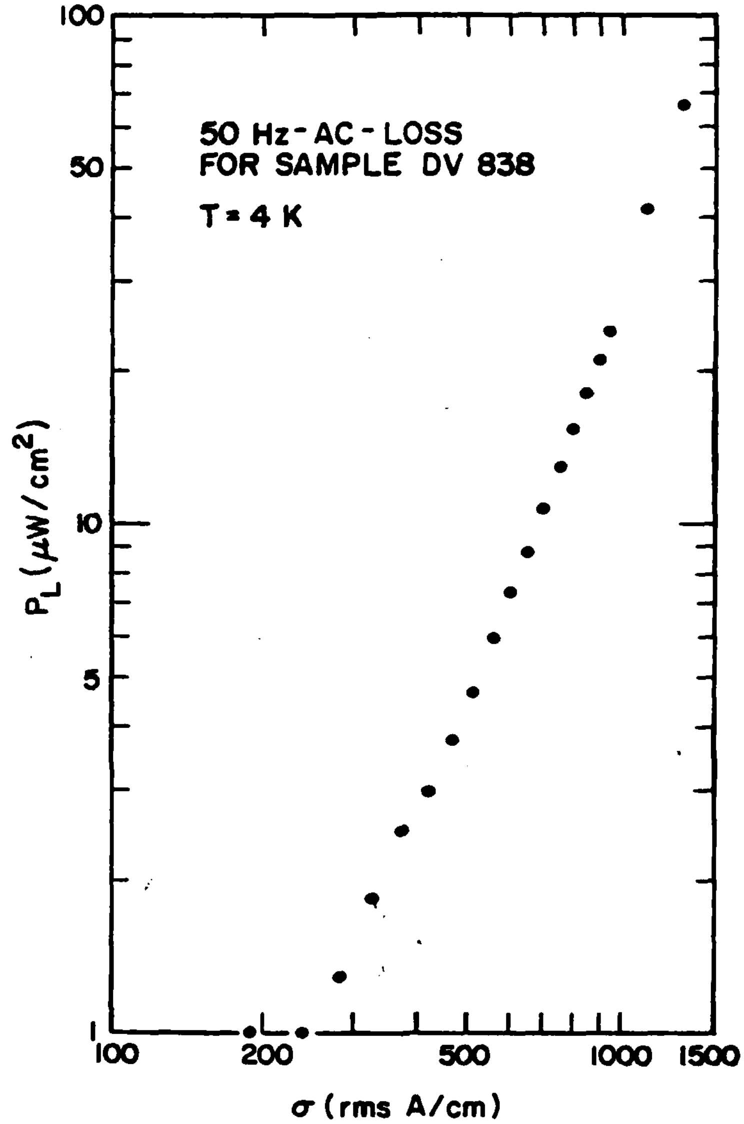
—TOP—

Plot of total AC losses and of the hysterictic component as functions of the induced current at 50Hz and 4K for 5.0 micrometer Ni_3 Ge coat on Cu substrate.



—TOP—

Plot of total AC loss as a function of induced current at 50Hz and 4K for a 2.8 micrometer thick Ni_3 Ge coat on Cu substrate.

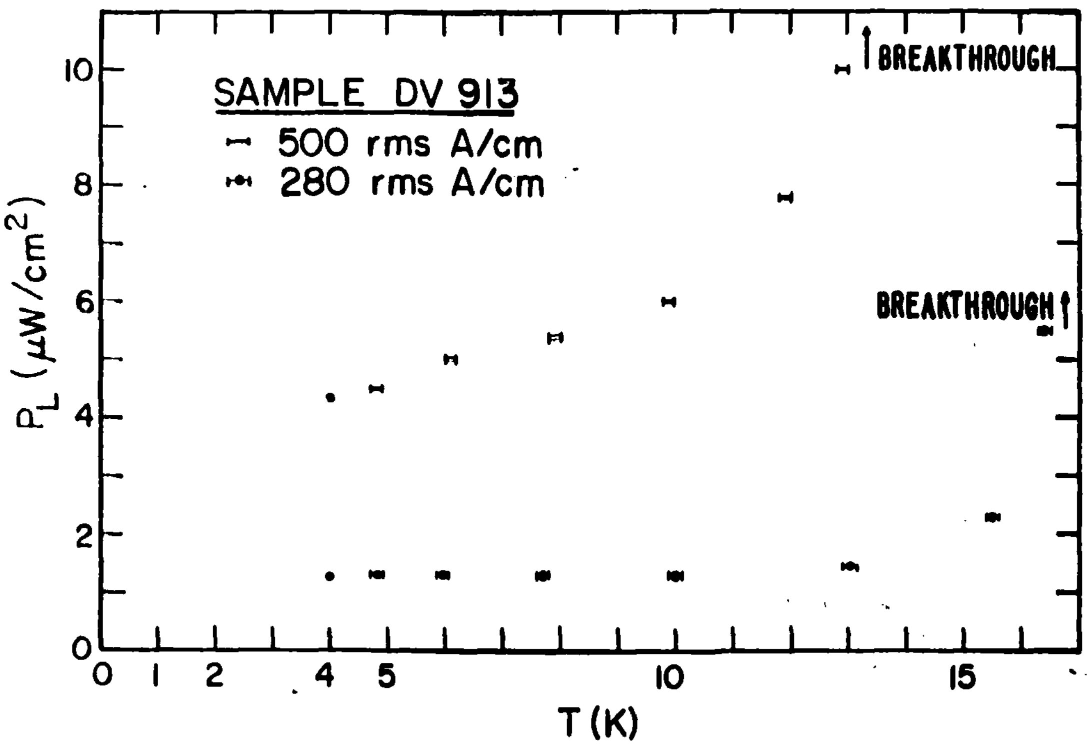


LASL 79-7
80 3230

CASL 130-7
80 3228

-TOP-

Plots of total AC losses at two induced current levels as functions of temperature at 50Hz for a 2.5 micrometer Ni_3 Ge coat on a Cu substrate.



SUPERCONDUCTIVITY STUDIES AT ARGONNE NATIONAL LABORATORY

Presented by Dr. K. E. Gray
Solid State Science Div.
Argonne National Laboratory
Argonne, Illinois

ABSTRACT

Superconductivity studies in the Solid State Division of Argonne National Laboratory can be divided into several related topics. Work is being conducted on the properties of superconductors that are removed from equilibrium by various perturbations (microwave and light irradiation, quasiparticle injection, and thermal gradients). Results of these studies have led to many applications. Additional research involves sputtered films of technologically important high T_c materials.

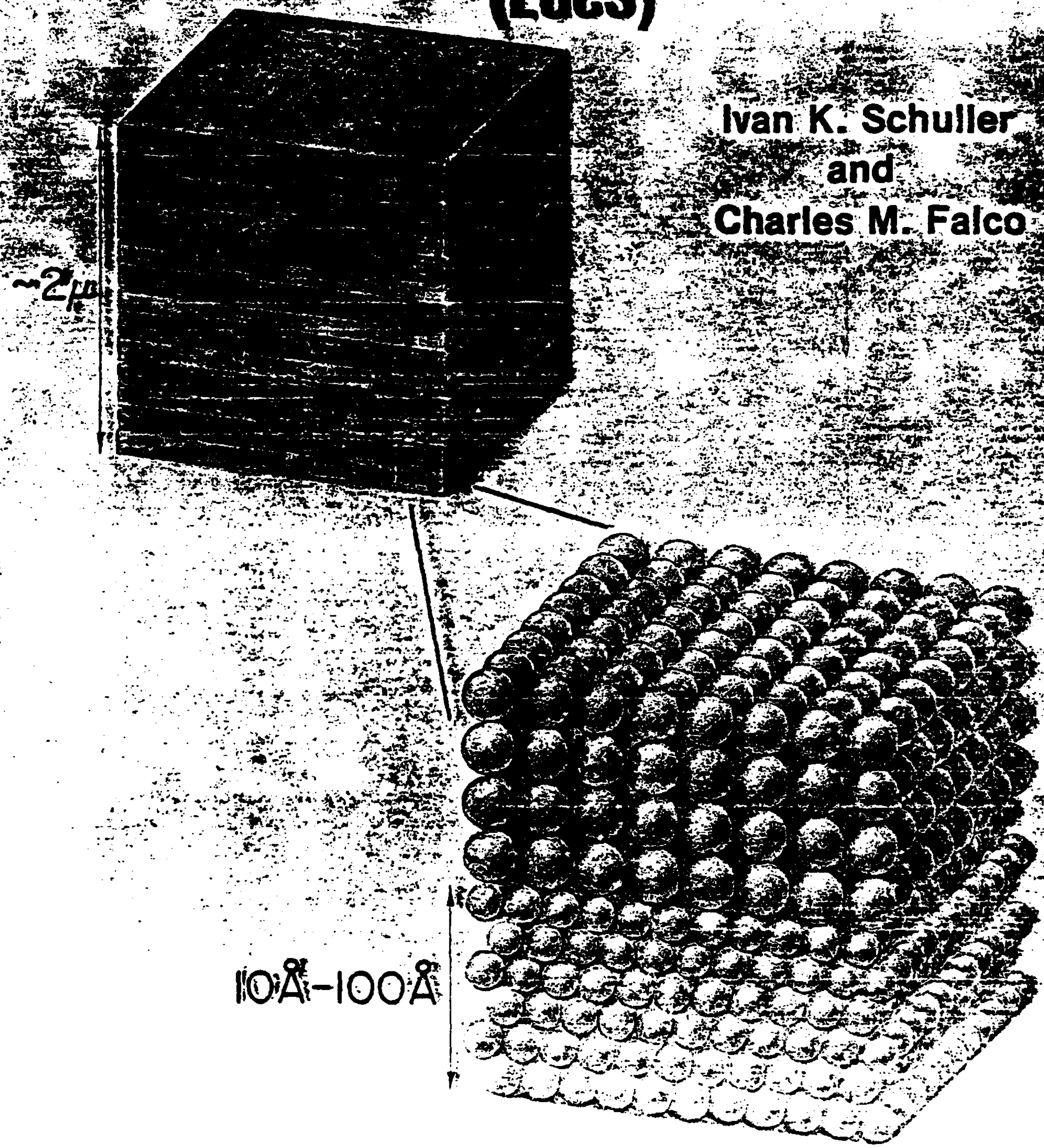
This talk will outline a fraction of the actual research being conducted. The nonequilibrium studies are of interest because all the uses of superconductors involve nonequilibrium states, but also because of a fundamental interest in nonequilibrium states in general physics. Superconductors provide an excellent system to study these, because there is a good microscopic theory of the equilibrium state (BCS), and because microscopic properties like the energy gap or order parameter and the quasiparticle distribution function can be readily measured by tunneling. Much of our work has concentrated on these measurements. Several ideas conceived during these studies have led to device applications. These include the Superconducting Tunnel Junction Transistor (which won the Industrial Research Magazine IR-100 Award for 1979) and the Superconducting Fault Current Limiter (a power switch).

A considerable effort to develop SQUID's (sensitive measuring devices) of high T_c sputtered films has resulted in the first operating SQUID's working at temperatures of about 15K. Such a development opens the scope of their use to include contained close-cycle refrigerators. As an outgrowth of this program, there is a considerable effort to use SQUID's in geophysical exploration.

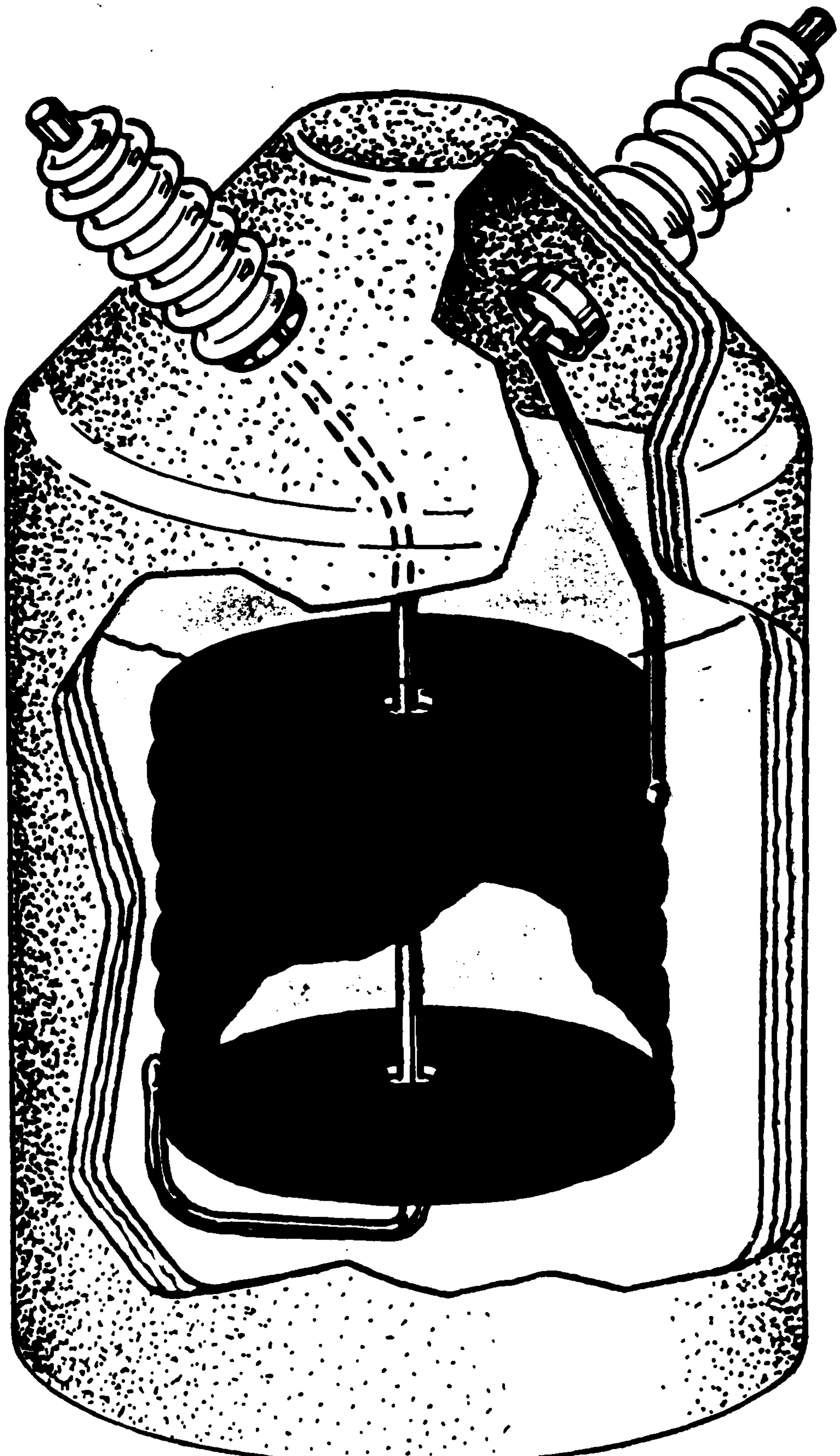
Recently, Layered Ultrathin Coherent Structures consisting of alternating thin film layers of two materials have been made with a remarkable degree of epitaxy extending throughout the layers. Initially, superconducting and transport properties have been measured, but the technique opens up a whole new area of potential for atomic engineering.

Layered Ultrathin Coherent Structures (LUCS)

Ivan K. Schuller
and
Charles M. Falco

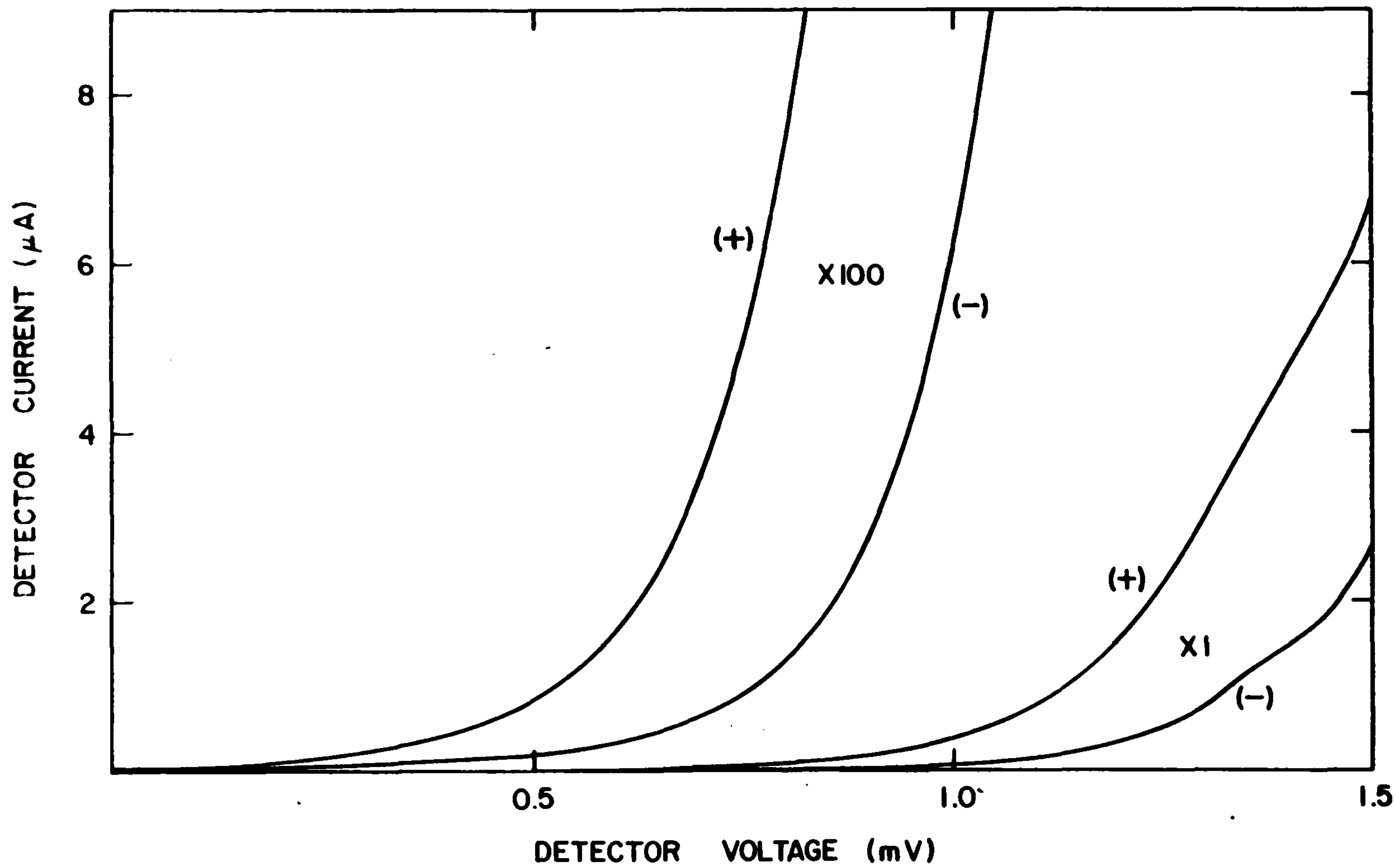


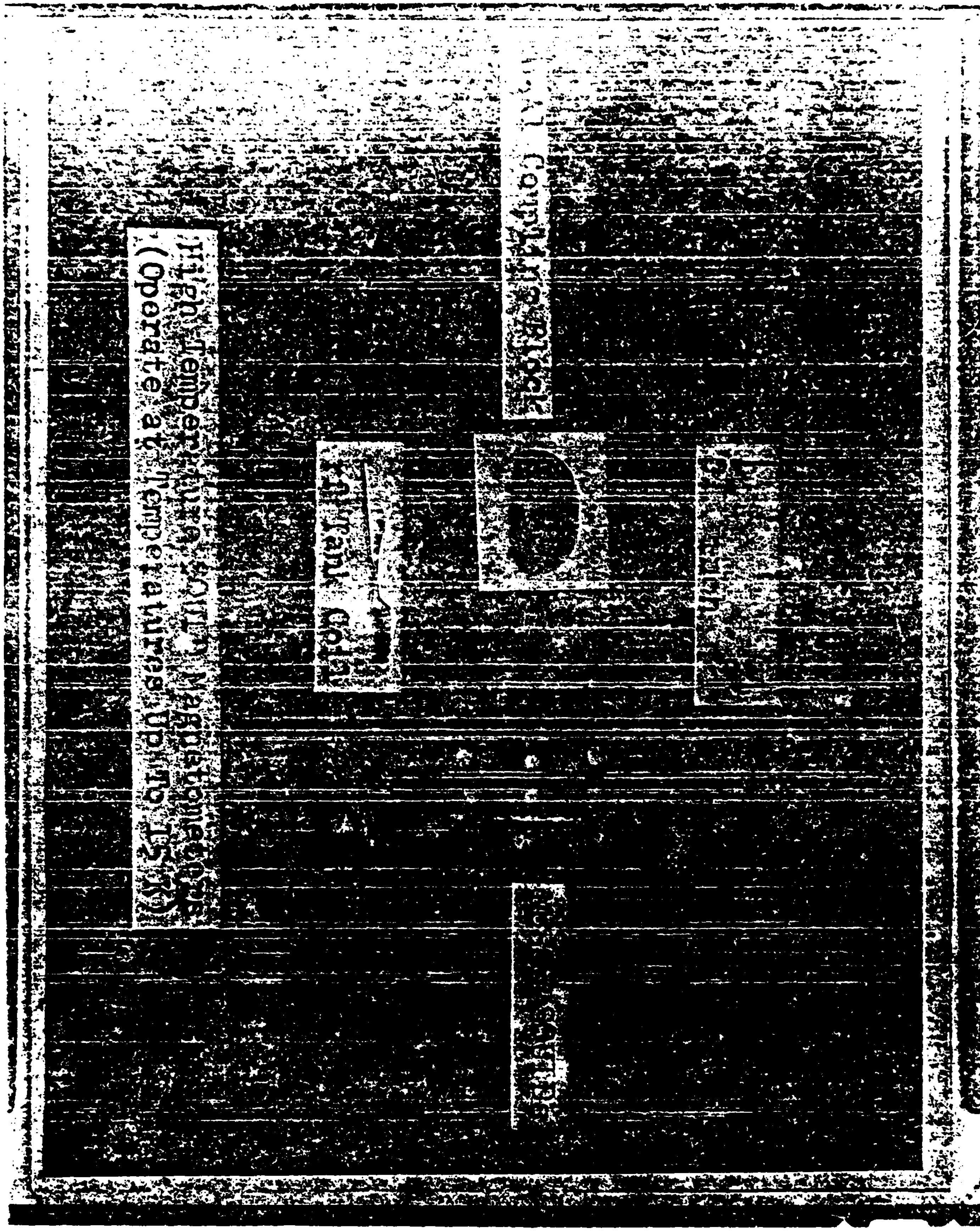
ARGONNE NATIONAL LABORATORY



An artists conception of a superconducting fault current limiter.

Current-voltage characteristics of a tunnel junction showing a non-equilibruim state of charge imbalance.





SUBJECT

3M CATALOG NO.

CFFF MHD MAGNET AT ARGONNE NATIONAL LABORATORY

Presented by Richard P. Smith
Argonne National Laboratory
Argonne, Illinois

ABSTRACT

ANL is directly involved in a number of areas related to the development of superconducting magnet technology. The broad range of applications for this technology includes magnetohydrodynamics (MHD), magnetic fusion energy (MFE), high energy physics, and accelerator technology development. In addition, basic research is conducted in the area of superconductor stability as applicable to pool-cooled magnets.

Currently a major effort of the Superconducting Magnet Group at ANL is devoted to the construction of a large 6T dipole magnet which will be transported to the University of Tennessee Space Institute Coal Fired Flow Facility (CFFF) for MHD Research. The magnet will provide a uniformly tapered field peaking at 6T in a 3m long bore, with entrance diameter 0.8m and exit diameter 1.0m.

Magnet system safety analysis is pursued at ANL, especially as it applies to large tokamak magnet systems for MFE. Pulsed coil and conductor development is pursued at ANL for the MFE program. A program is underway to construct a model thin solenoid for application to a high energy physics particle detector. A 60 T/m gradient quadrupole magnet for accelerator beam transport is under design at ANL. The quadrupole is a prototype for a system of 16 such magnets required at Fermi National Accelerator Laboratory.

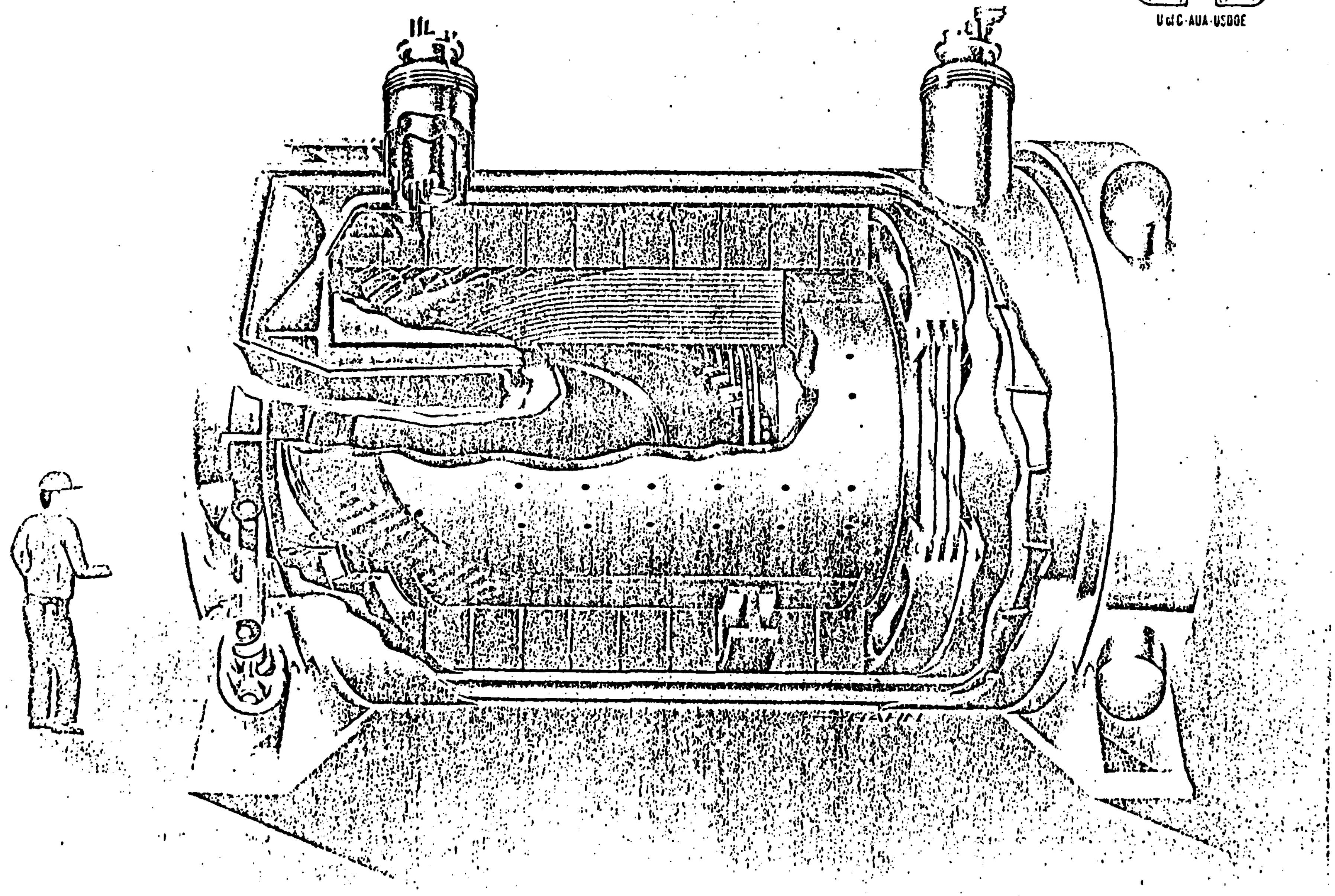
A 6T mass-analyzer magnet is under construction for the ATLAS heavy-ion facility at Argonne. The magnet will provide 45 degrees of bend and together with its twin will replace a conventional 90 degree analyzer in the existing facility. The increased bending power of the superconducting analyzer will allow the acceleration of high quality beams of ions as heavy as uranium, with projectile energies up to 25 MeV/A.

UTSI

COAL-FIRED FLOW FACILITY SUPERCONDUCTING MHD MAGNET

ARGONNE NATIONAL LABORATORY

UofC·AUA·USDOE



CFFF SUPERCONDUCTING MAGNET SYSTEM

OBJECTIVES

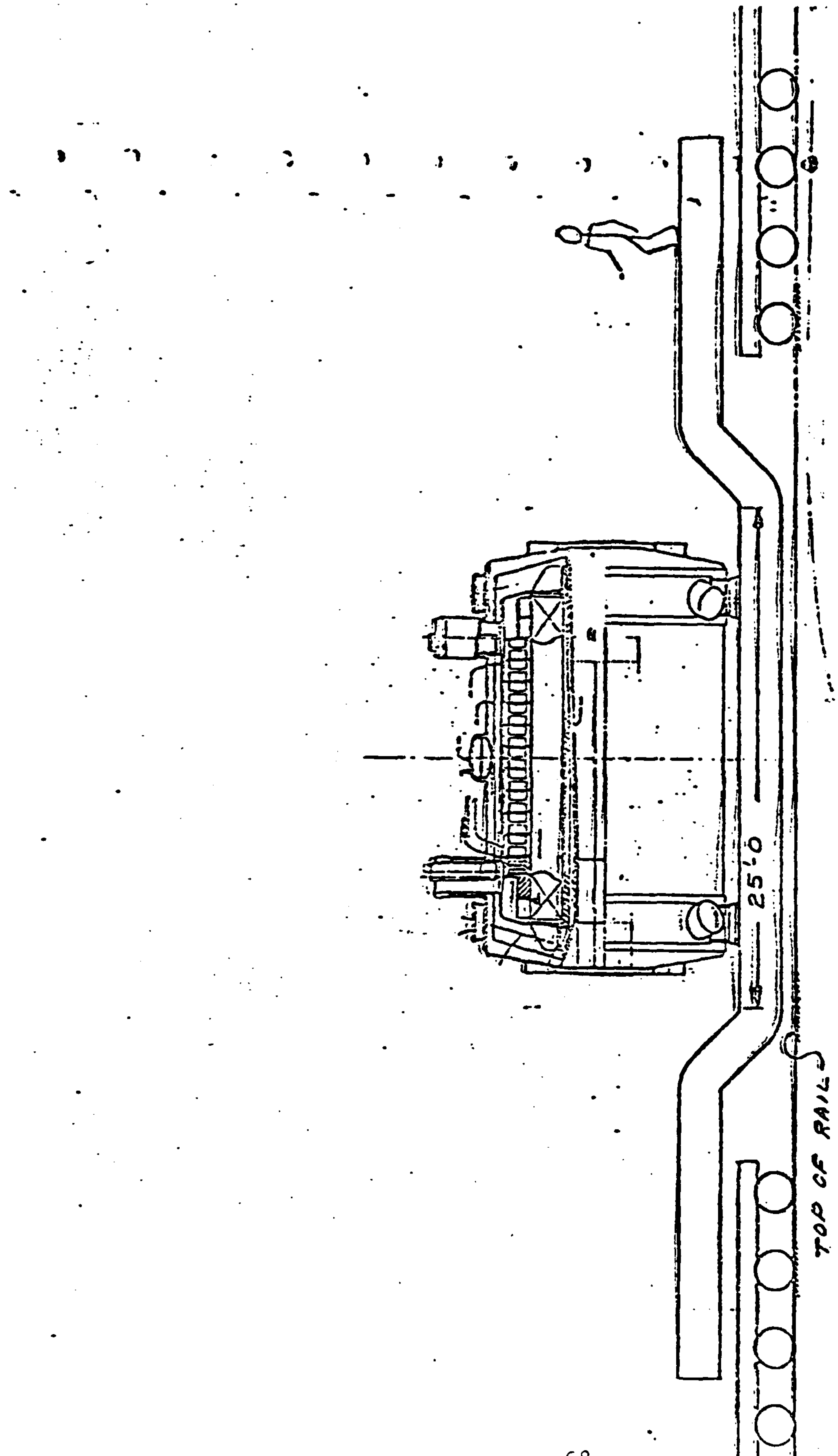
1. DESIGN, DEVELOPMENT, FABRICATION AND TESTING OF THE CFFF SUPERCONDUCTING MAGNET, MAGNET CRYOSTAT, INSTRUMENTATION AND CONTROL EQUIPMENT.

2. PROCUREMENT AND ASSEMBLY OF A COMPLETE CRYOGENIC SYSTEM.

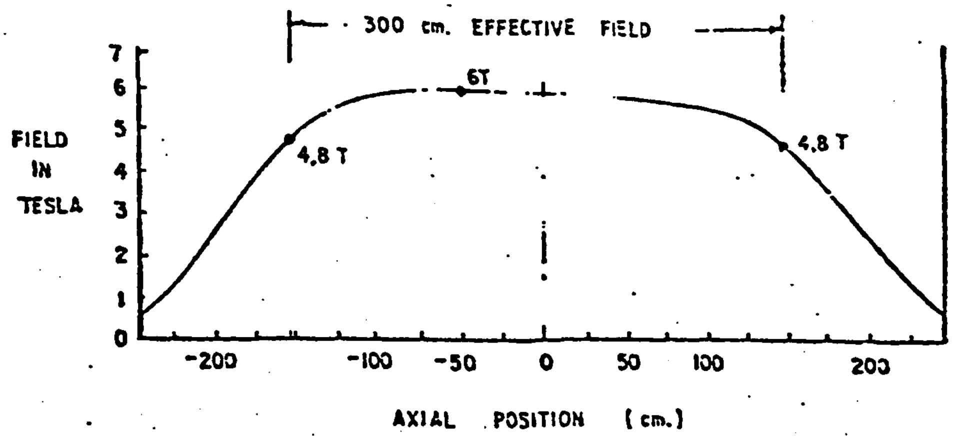
3. SHIPPING, INSTALLING, COMMISSIONING AND MAINTENANCE OF THE COMPLETE MAGNET, CRYOSTAT, CRYOGENICS, POWER SUPPLY, AND CONTROL AND PROTECTING INSTRUMENTATION.

4. DEVELOPMENT OF THE SUPERCONDUCTING MHD MAGNET TECHNOLOGY FOR CFFF SCMS AND FOR FUTURE LARGER MHD MAGNETS.

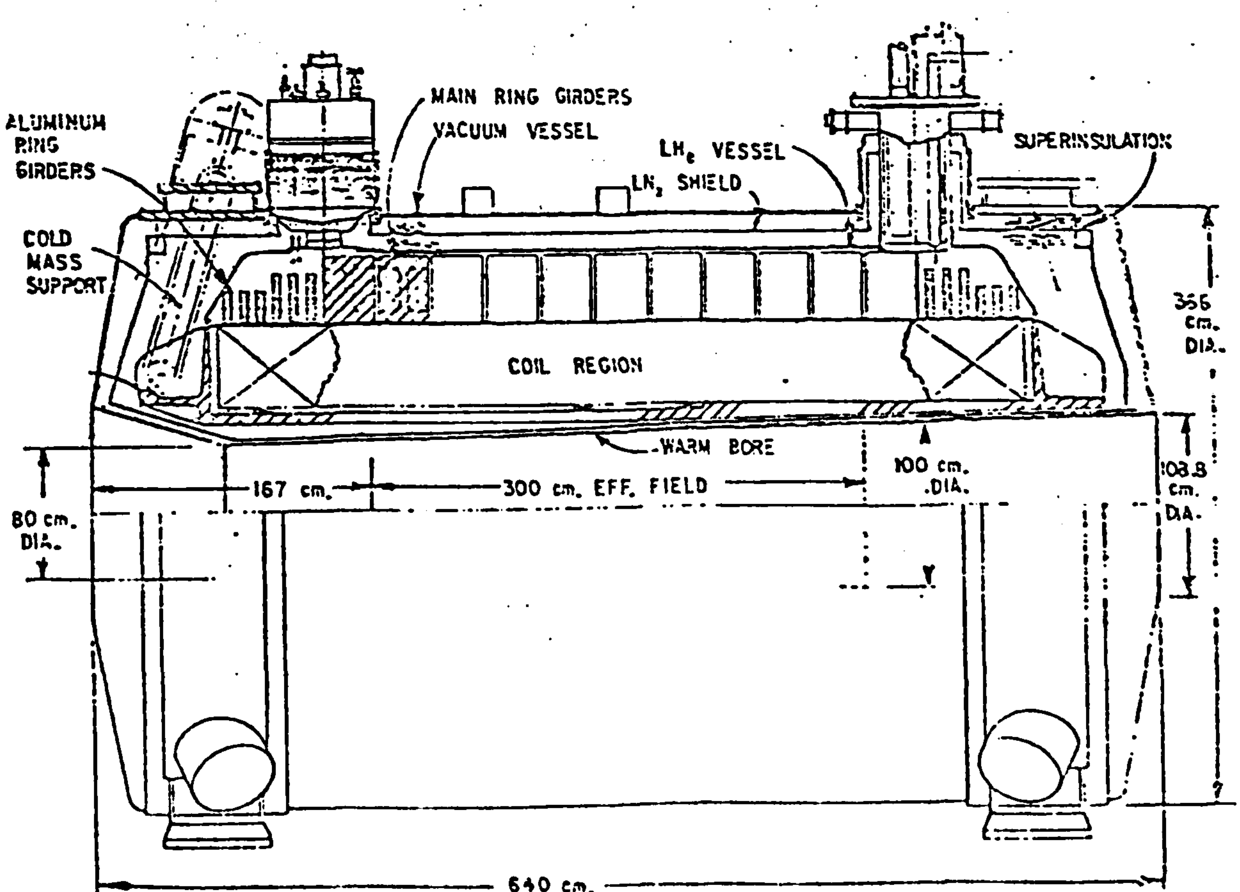
5. FOLLOW THROUGH AND DOCUMENTATION OF OPERATING EXPERIENCES OF CFFF SCMS.



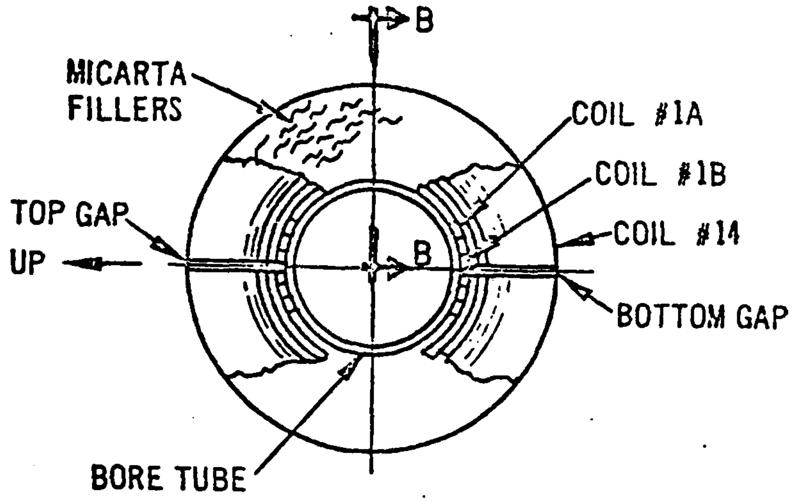
Transportation Detail.



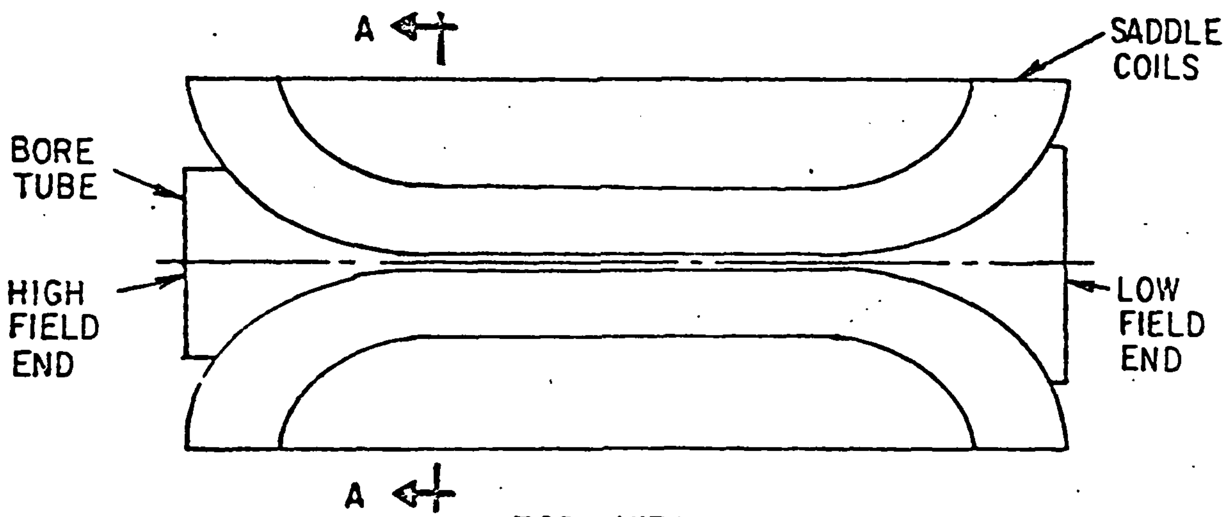
Magnet Overall Detail



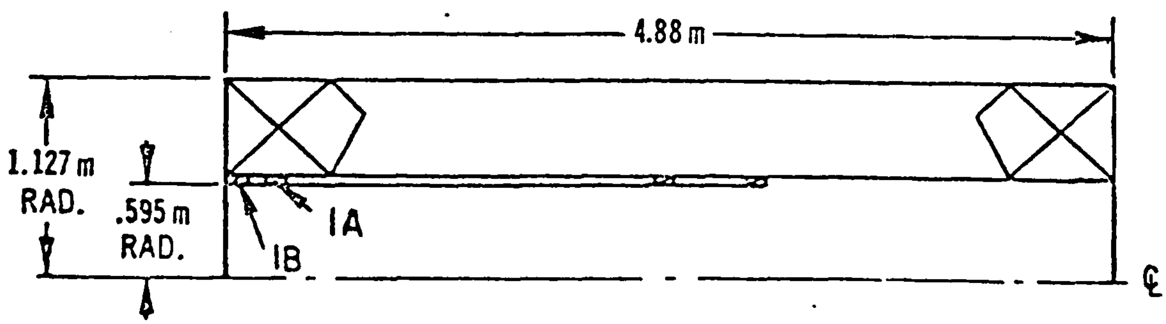
CFFF Coil Winding Detail



SECTION A-A

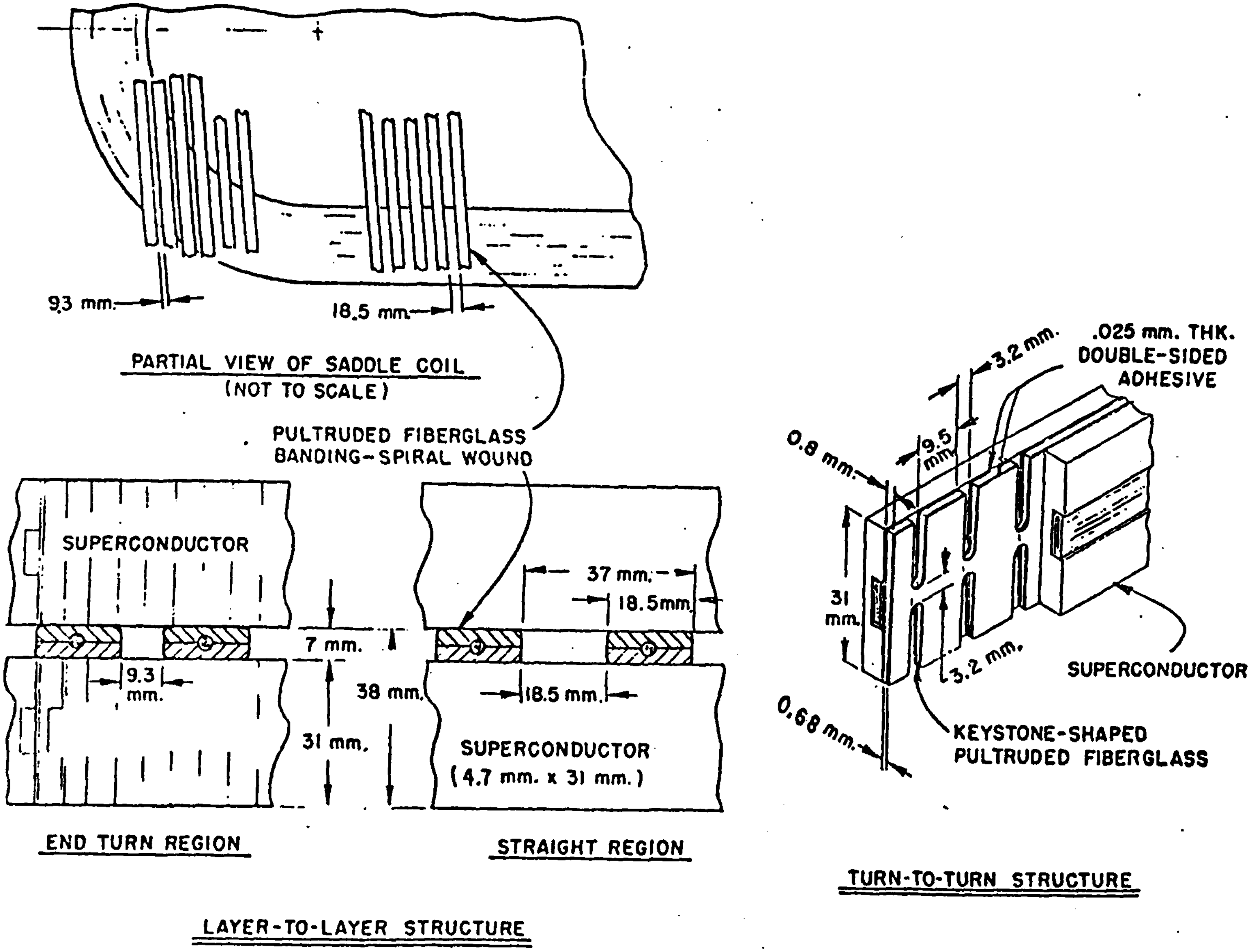


TOP VIEW

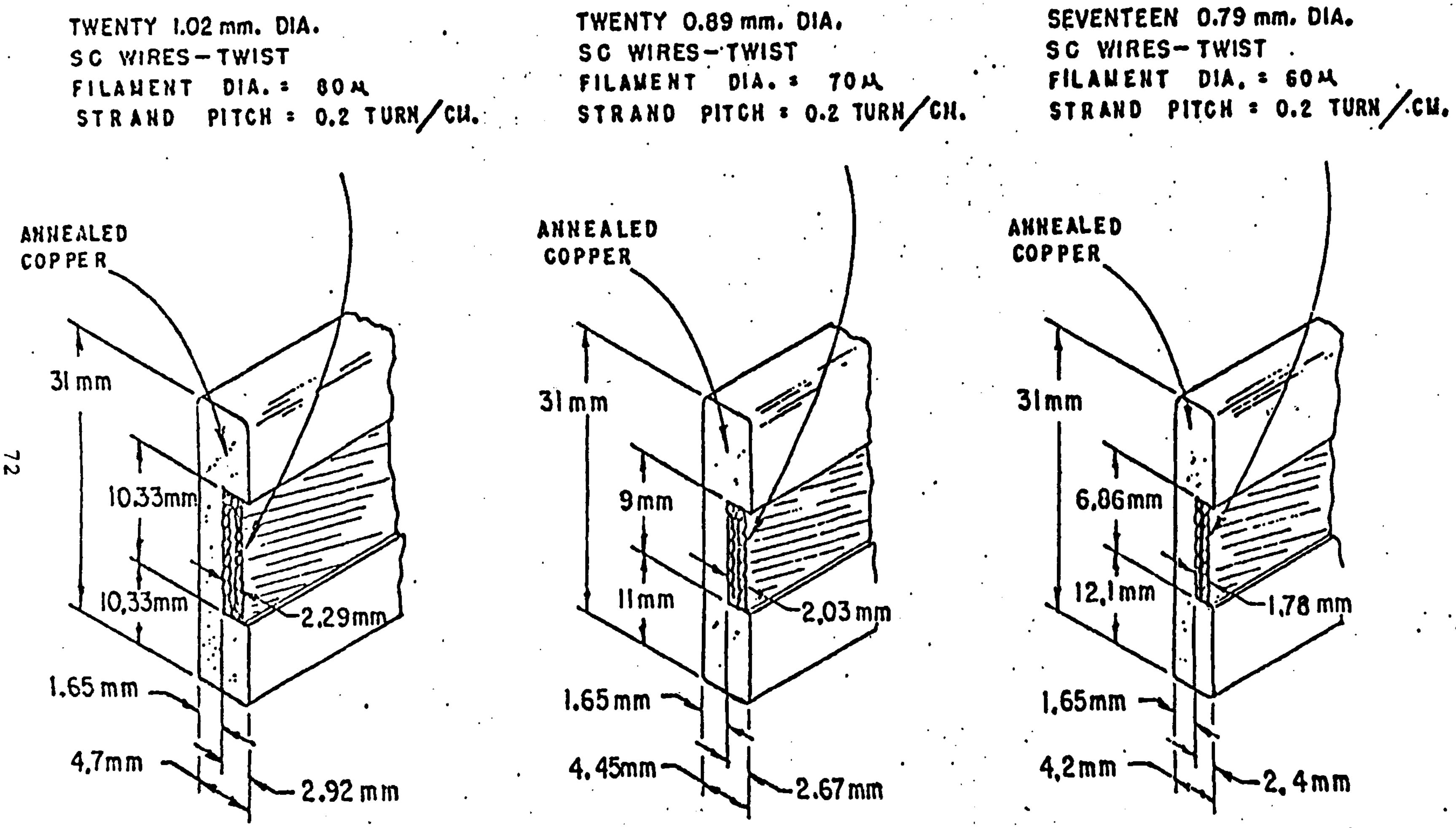


SECTION B-B

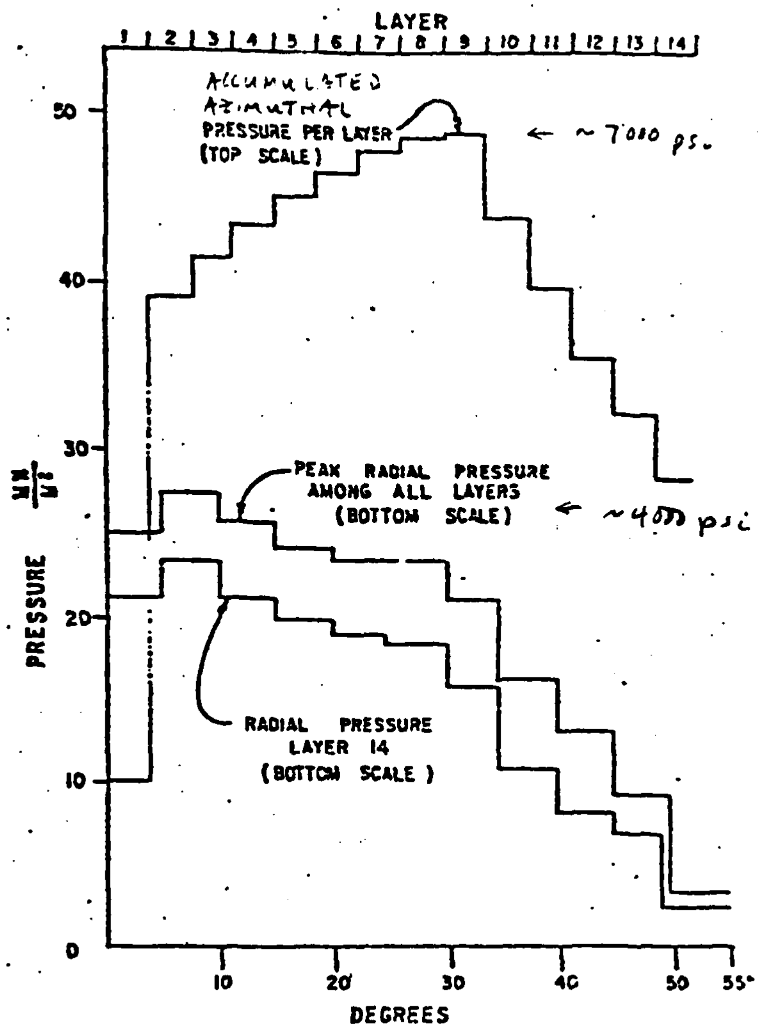
Conductor Insulating Detail.

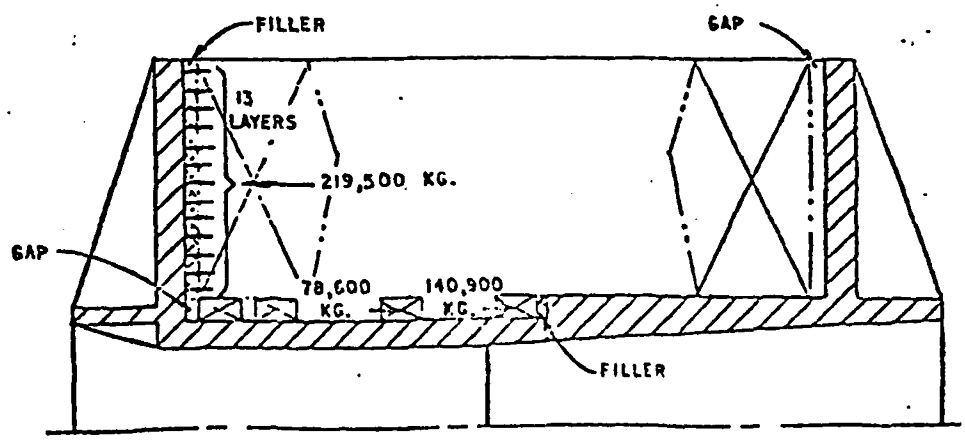


Conductor Detail

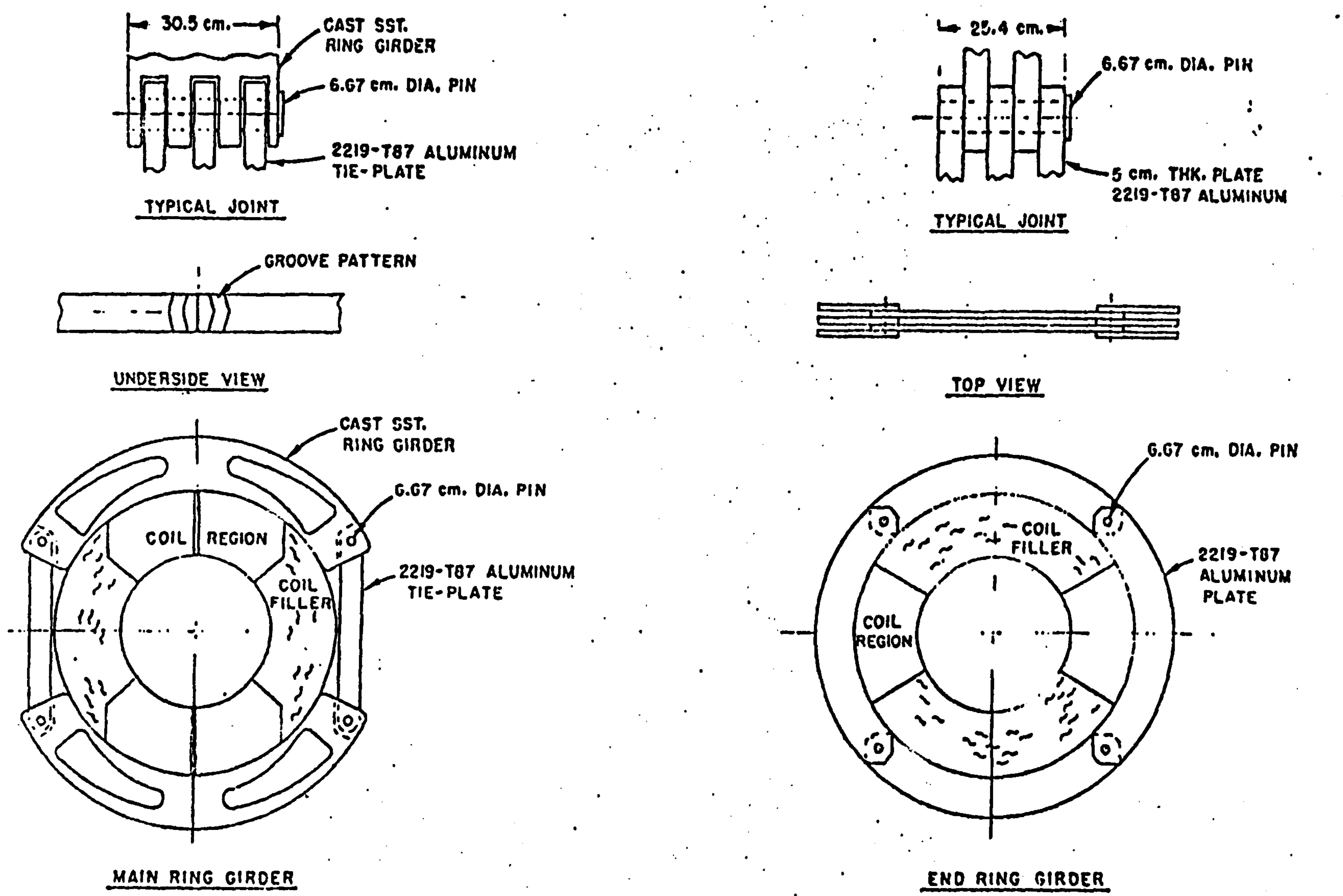


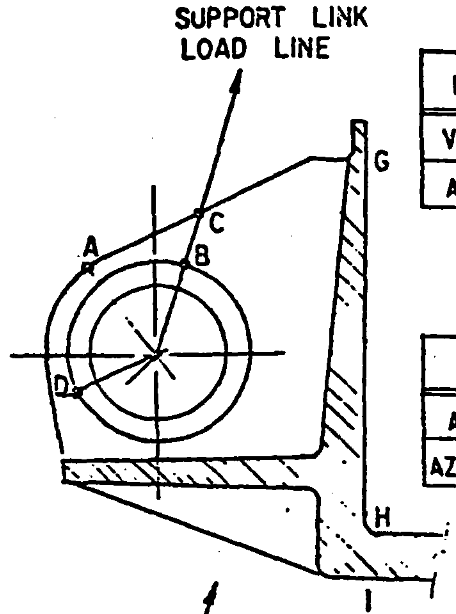
Lorentz Force Detail





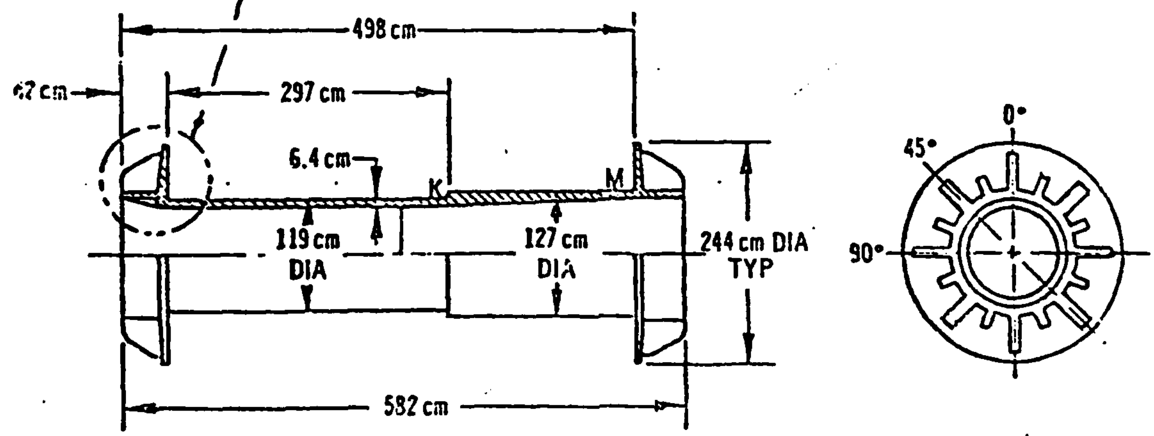
Coil Support Detail





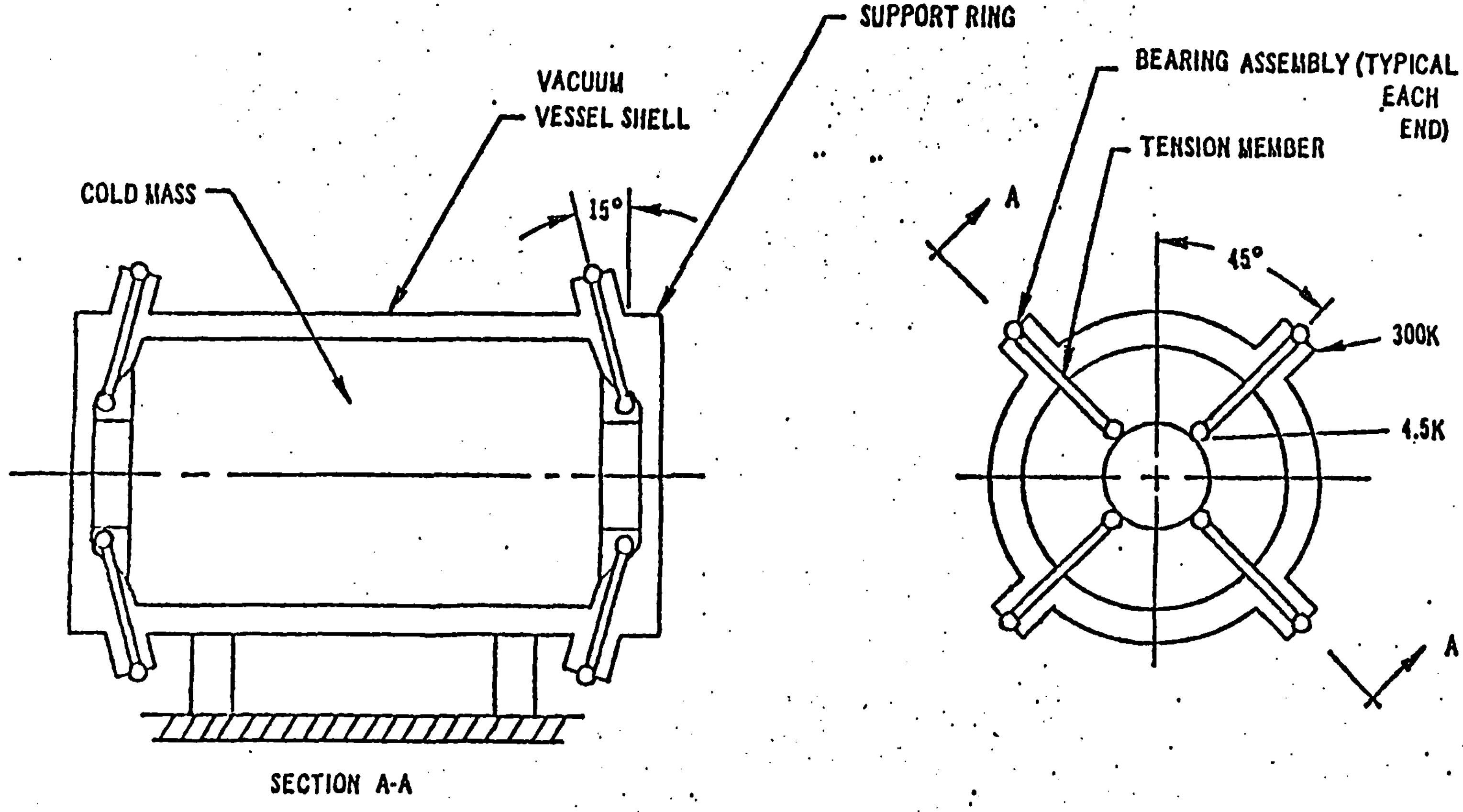
LOADING	A	B	D
VERTICAL ($\frac{MN}{m^2}$)	210	186	172
AXIAL ($\frac{MN}{m^2}$)	252	223	207
	SHIPPING		

LOADING	G	H	I	K	M
AXIAL ($\frac{MN}{m^2}$)	—	339	-250	88	140
AZIMUTHAL ($\frac{MN}{m^2}$)	33	147	29.6	14	62
	MAGNETIC LOADING PLUS HELIUM PRESSURE				

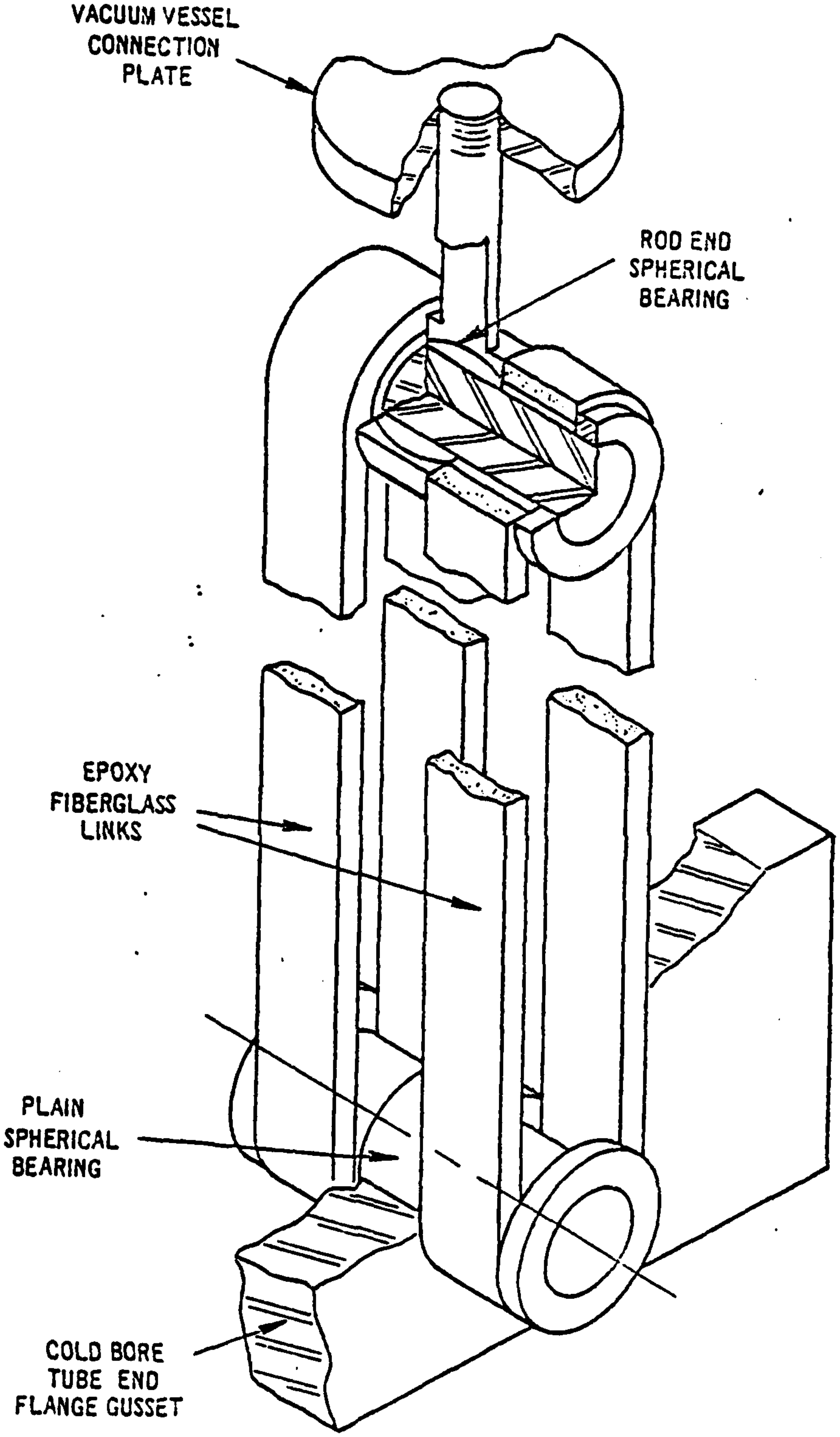


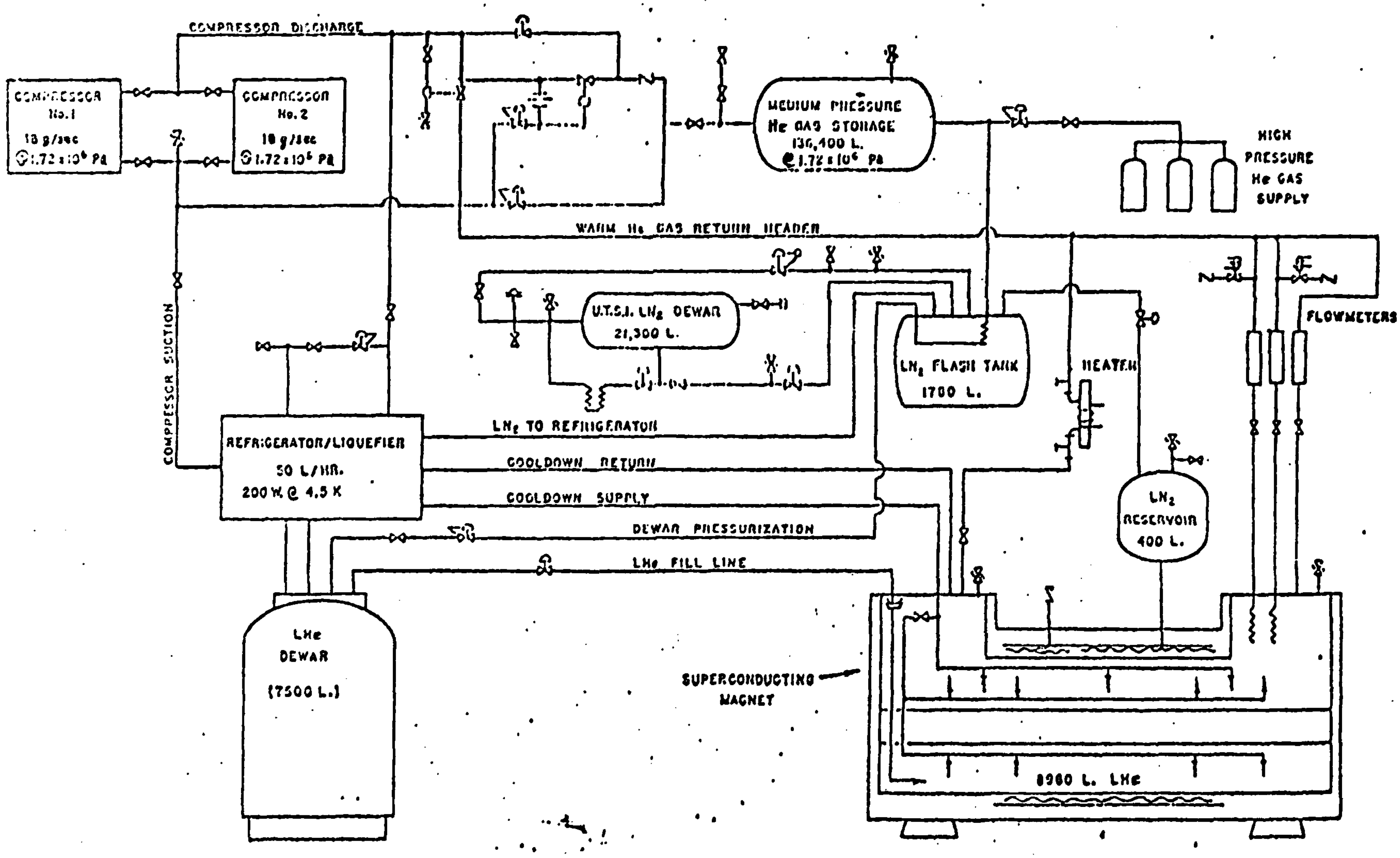
BORE TUBE & END FLANGES

Cold Mass Support Detail



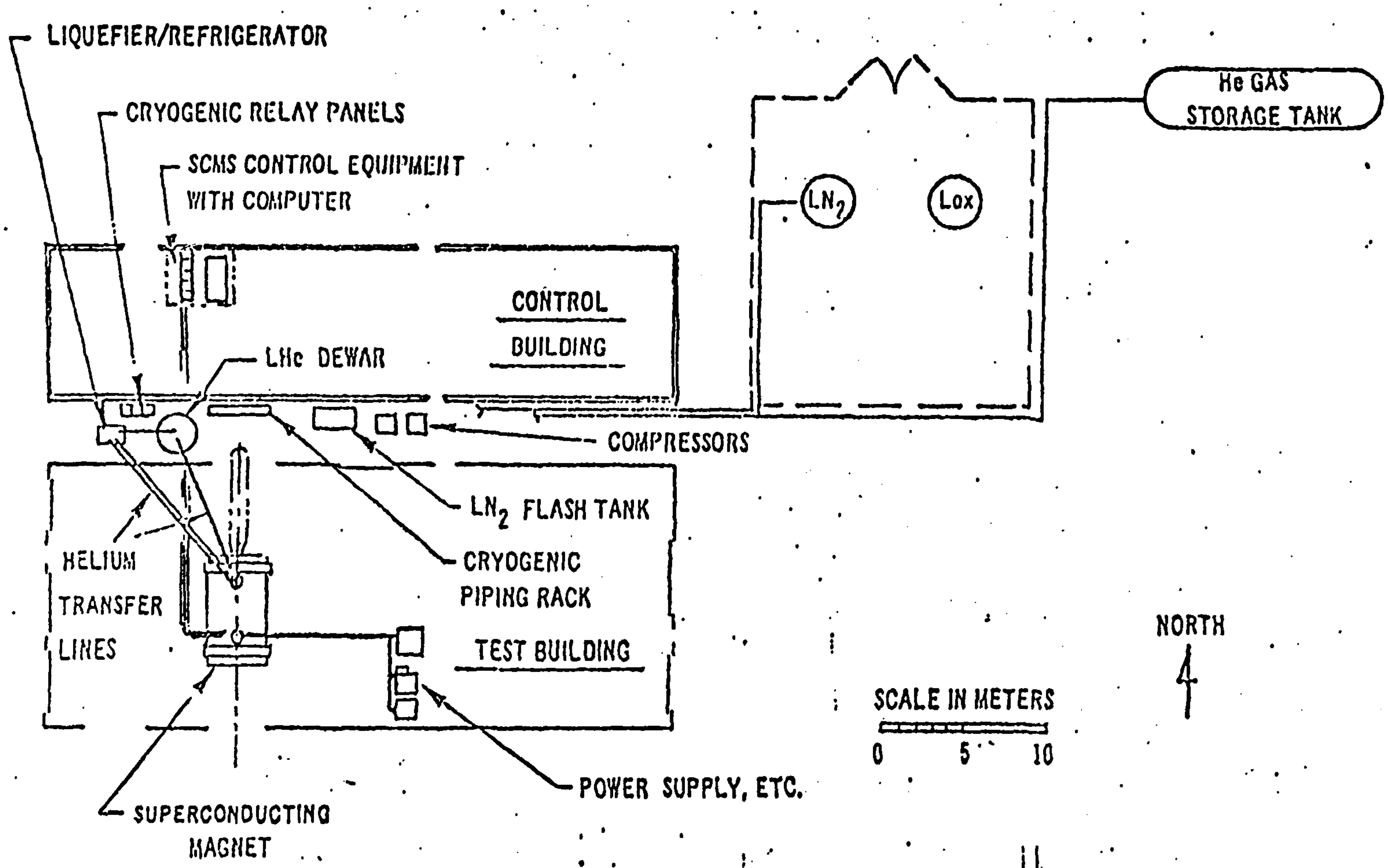
Cold Mass Support Link .



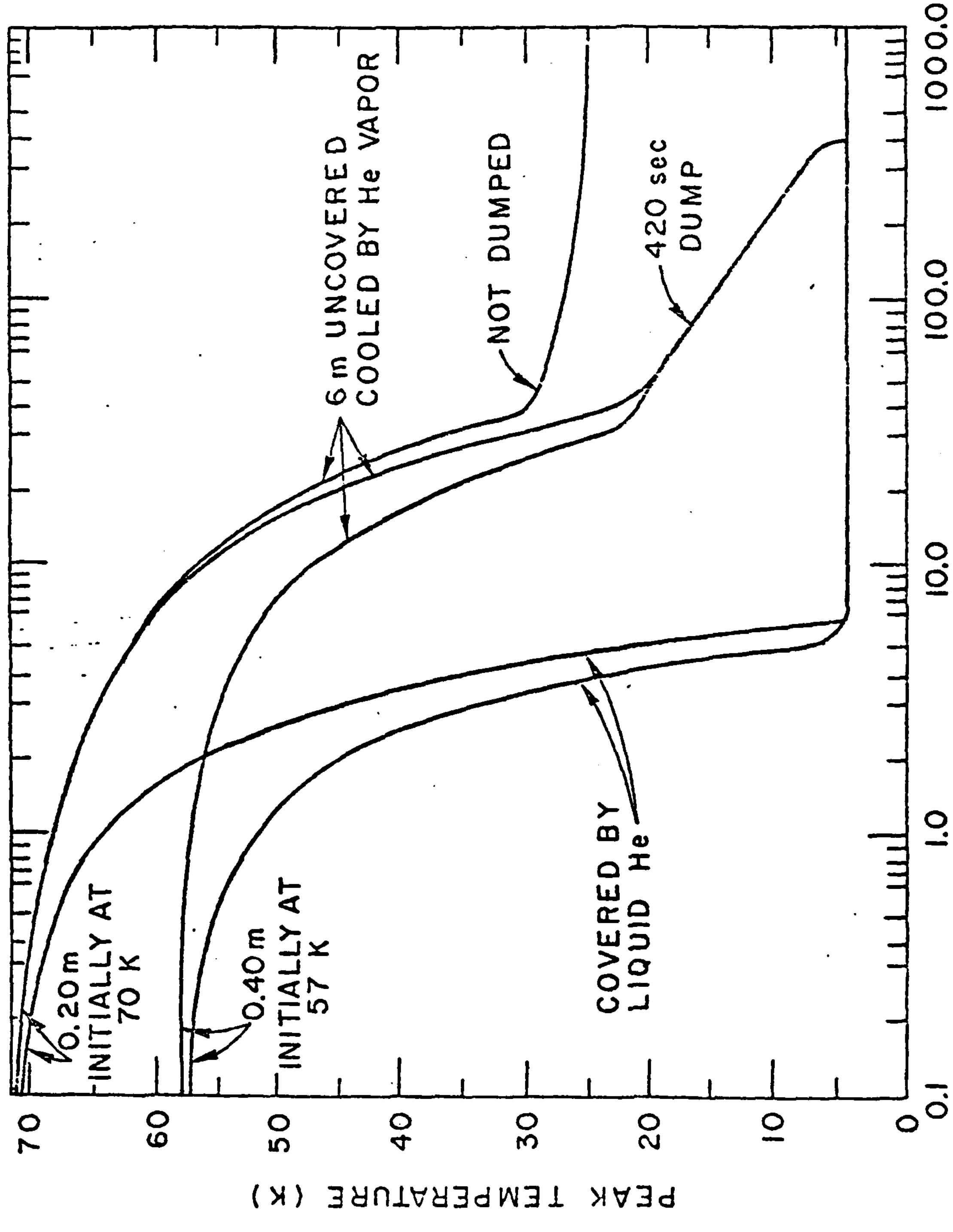


Magnet Cryogenic System.

Cryogenic System Layout at UTSI



Stability Calculation Results for CFFF.



MHD SUPERCONDUCTING MAGNETS

Presented by Robert J. Wright
Department of Energy
Fossil Energy
Office of MHD
Washington, D.C.

ABSTRACT

Magnetohydrodynamic (MHD) electrical power generation is based on the principle that a conducting fluid flowing through a magnetic field will generate an electric field which is perpendicular to both the flow direction and the field direction.

In the MHD generators now being evaluated for commercial use, the fluid conductor is very hot gas from air-enriched combustion of coal. To increase conductivity the gas is seeded with a salt such as potassium carbonate, K_2CO_3, which becomes ionized at the high gas temperatures achievable in an MHD generator. The high conductivity gas is accelerated through a nozzle and flows at high velocity through an enclosed channel located in the field of a large superconducting magnet. An array of electrodes along the channel wall is suitably connected to a load. Current is thus extracted directly from the gas without any moving parts and power is delivered to the load.

Because there are no moving parts, the MHD generator can operate at much higher temperatures than a conventional turbine. The exit gas from the MHD channel is still hot enough to operate a conventional steam turbine plant. The exit gas from the MHD "topping plant" added to a steam turbine plant can thus increase the amount of electric power generated from each ton of coal burned by approximately 50%.

In addition to this very high compa[illegible]tive thermodynamic efficiency, it is inherent in the MHD combustion process [illegible]at SO_x and MO_x emissions are reduced well below EPA standards, even with high sulphur coals.

The ability to burn indigenous coal directly and cleanly to produce [illegible] electric power is of great importance to the U.S. energy economy.

The magnetic field strength required for practical MHD power [illegible] tesla (60,000 gauss). This is approximately 250,000 times [illegible] field of a strong permanent magnet.

The field for the MHD generator is produced by passing a D.C. current through many turns of conductor in a specially shaped winding. This is called an "air-core electro-magnet". If the conductors of the winding were made from conventional copper wire, the magnet would require an amount of power nearly equal to the output of the MHD generator. It is thus necessary that the magnet windings be made from superconductors.

The superconducting magnets that will be required for commercial scale MHD power generation plants will be large--about 25 meters in length, and heavy--about 4000 metric tons. They will be sophisticated in design and will involve many subsystems of an advanced technological nature.

The United States Department of Energy sponsors an active program in superconducting MHD magnet technology development that includes both procurement of magnets of increasing scale and advanced magnet technology to support the next generation of devices. The technology development programs have involved the industrial community to the maximum extent to build a suitable base to prepare for the full scale magnet which must be built before the end of the century.

The Massachusetts Institute of Technology, Francis Bitter National Magnet Laboratory serves as the Department of Energy, Office of MHD field office for superconducting magnet technology. A number of facilities nation-wide are involved in MHD research and development. A magnet system is required for each of these facilities, and each magnet system and each facility is part of a development plan that will permit the evaluation of a number of alternate magnet designs, and test all system components rigorously in increasing scale.

The High Performance Demonstration Experiment (HPDE) located at the Arnold Engineering Development Center in Tullahoma, Tennessee uses the largest magnet constructed for MHD experiments to date. The magnet is cryogenic, but not superconducting; it can be operated using either water or liquid nitrogen for cooling and can reach a magnetic field strength of 6 tesla for short periods of time. The magnet is 9 meters long and about 3.25 meters high. It weighs 265 tons and is being used to test a number of channel designs and to demonstrate high enthalpy extraction.

The Component Development and Integration Facility (CDIF) situated in Butte, Montana, will provide an opportunity to test all the components of an MHD electrical power generator system and to see how these components interact. The facility has two magnet systems. One of them, a conventional water-cooled copper electromagnet produces a peak field of 3.0 tesla and will be used for initial work before the superconducting magnet system is installed in 1982. The superconducting magnet system for CDIF will be the largest superconducting magnet yet constructed for MHD. It is about 10 meters long and 4 meters high and weighs about 200 tons. Its main design feature places the rectangular saddle magnet windings in a fiberglass-reinforced epoxy substructure that supports the winding and carries much of the magnetic forces. This concept of using a substructure to separate and support individual turns of the electromagnetic winding is being explored for use in the much larger magnets needed for commercial MHD power generators.

The CDIF conventional magnet was built by Magnetic Corporation of America and the CDIF superconducting magnet is being built by the General Electric Company, both under the supervision of the Massachusetts Institute of Technology, Francis Bitter National Laboratory.

The Coal-Fired-Flow Facility (CFFF) is located at the University of Tennessee Space Institute in Tullahoma, Tennessee. This facility will investigate channel operation under high slagging conditions produced from coal combustion with little or no slag rejection in the combustor. The superconducting magnet for the CFFF uses a magnet design concept in which the magnet windings are not carried in substructural support. A similar design principle was used in the construction of the superconducting magnet for the U-25 Bypass facility at the Institute for High Temperatures in Moscow. Both the CFFF and the U-25 B magnets were designed and constructed by Argonne National Laboratory. The U-25 B has a maximum field of 5 tesla, is 4 meters long and weighs 40 tons while the CFFF magnet has a maximum field of 6 tesla, is 10 meters long and weighs 180 tons.

The Stanford University High Temperature Gas Dynamics Laboratory located in Palo Alto, California specializes in studies of MHD instabilities in the plasma. These studies require a uniform magnetic field higher than that required for combustor or channel studies. For that reason a magnet with an extremely uniform field of at least 7 tesla on-axis has been designed. General Dynamics is incorporating the CASK superconducting magnet design concept into this effort.

The magnets now planned and under construction for the MHD experimental facilities noted above are the first stepping stones toward reaching commercial-scale magnets in baseload MHD power generating plants. Each of these magnets, and the facility with which it is associated, is geared to investigate areas that will permit taking the next step toward commercilization. Because of the differences in magnet designs, a number of alternative concepts and manufacturing methods are being tested. The completion and operation of these magnets will permit a final choice of a magnet design for an MHD Engineering Test Facility (ETF). Preliminary designs for such magnets are already being considered, all of which use structural design concepts aimed at scale-up. Not until the operational data from the smaller magnets are assessed will the next much larger step be taken. It is essential that an ETF magnet make optimal use of structural materials as this is the largest percentage of magnet weight and cost.

FERMILAB'S ENERGY SAVER

Presented by M. Kuchnir
Fermi National Accelerator Laboratory*
Batavia, Illinois

ABSTRACT

A 1TeV synchrotron based on superconducting magnets is under construction at the Fermi National Accelerator Laboratory. Its 779 beam bending dipole magnets and its 216 beam focusing quadrupole magnets form a 6km long ring kept at 4.6 K by means of twenty-four 700w satellite refrigerators and one 5000 liter/hour Helium Liquefier. The facilities built for developing, producing, measuring, and refrigerating these magnets are unique. To date 320 of these dipole magnets have been built. The 4.3 T field they generate is uniform to 1 part in 10^4 over 6m long cylindrical volumes of 5cm diameter perpendicular to the axis. Strings with up to 40 magnets have been installed and activated in the tunnel that houses the present 0.5 TeV synchrotron. A 20 magnet string above ground is now being used for system tests, especially quench handling tests. Besides doubling the maximum energy of the proton beam, the new synchrotron will considerably reduce the laboratory's power consumption.

*Operated by Univ. Res. Association for the Dept. of Energy

LCP AND 12 TESLA PROGRAMS AT ORNL

Presented by W. A. Fietz
Oak Ridge National Laboratory
Oak Ridge, Tennessee

ABSTRACT

The Large Coil Program (LCP) at ORNL consists of six coils and a test facility for proving the use of superconducting coils in tokamaks. Each of the six coils is built to a common external specification with a 2.5 x 3.5m bore and an 8 T magnetic field. Each is designed and manufactured by a different company, three in the U.S. and three from abroad. The conductor and winding schemes vary widely so that a great deal of experience with different conductors will result from the tests. The first coils are expected in mid FY 1981, and the full tests of all six coils is scheduled in FY 1983. The 12 T program is designed to produce conductor experience in smaller coils to extend the operating field to 12 Tesla. Four teams in the U.S. will each produce a model coil of 1m OD by 0.4m ID for testing in the High Field Test Facility at LLL. The schedule calls for the first coils to be delivered in FY 1981.

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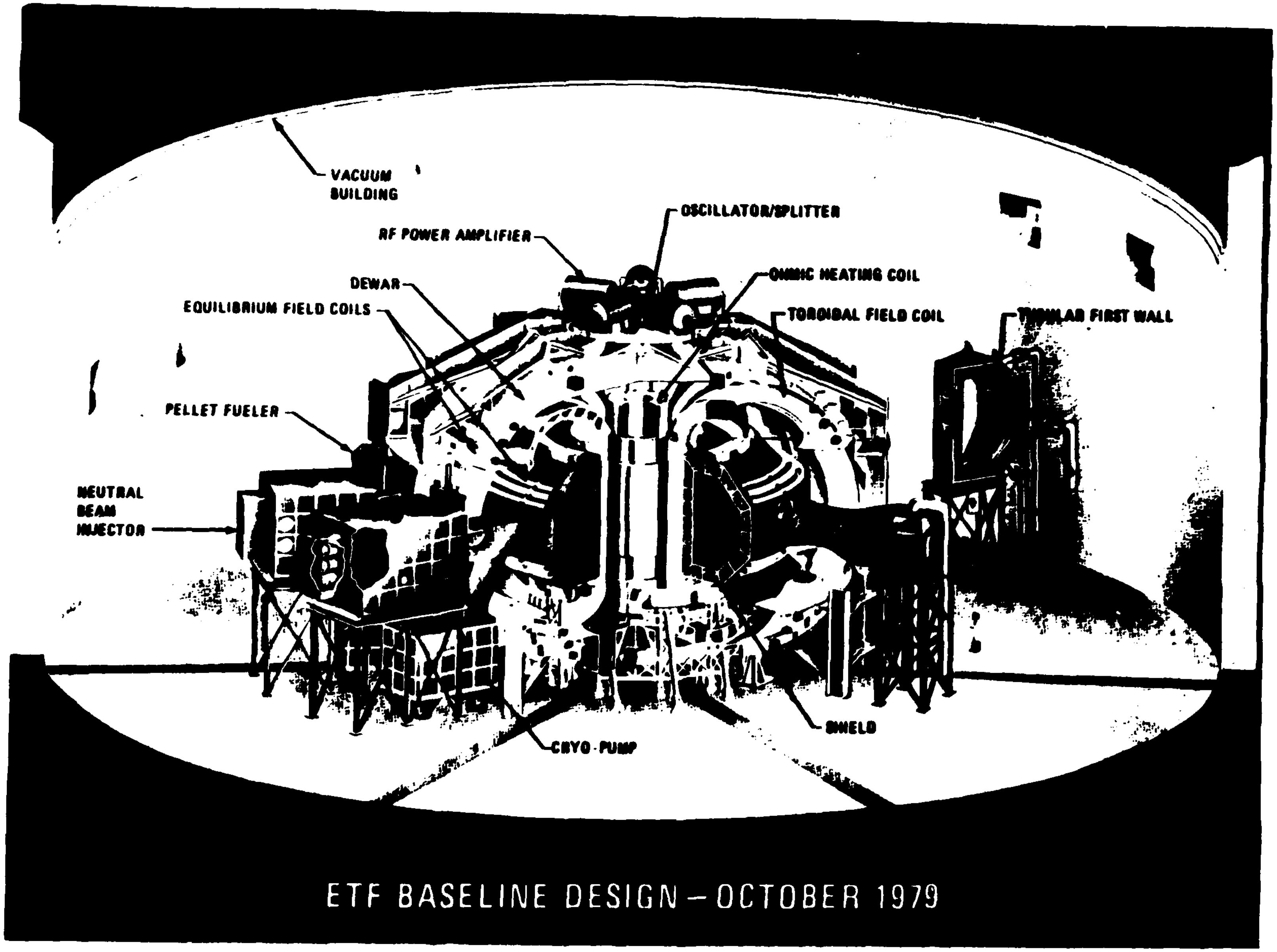
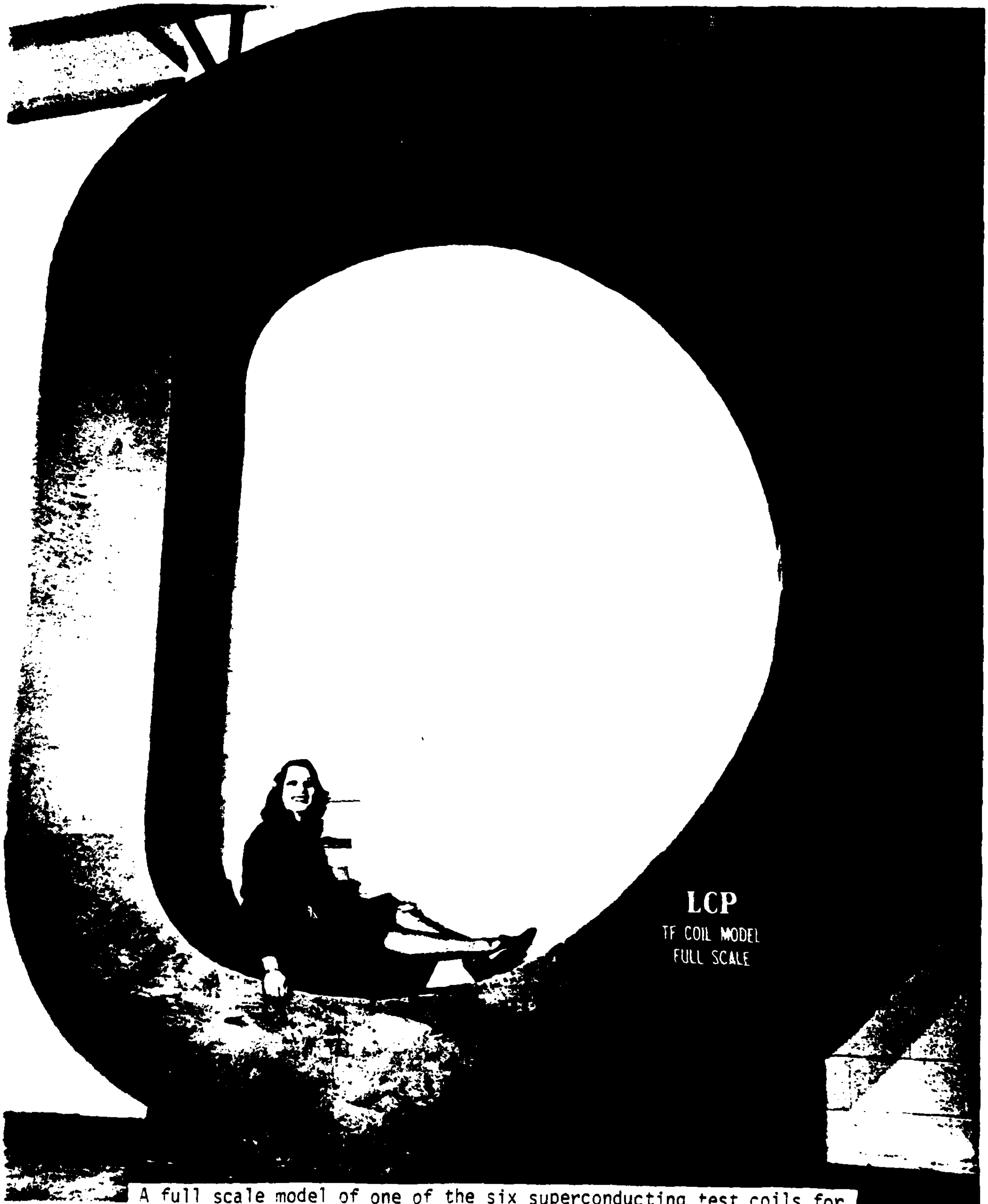
VIEWGRAPH TITLES

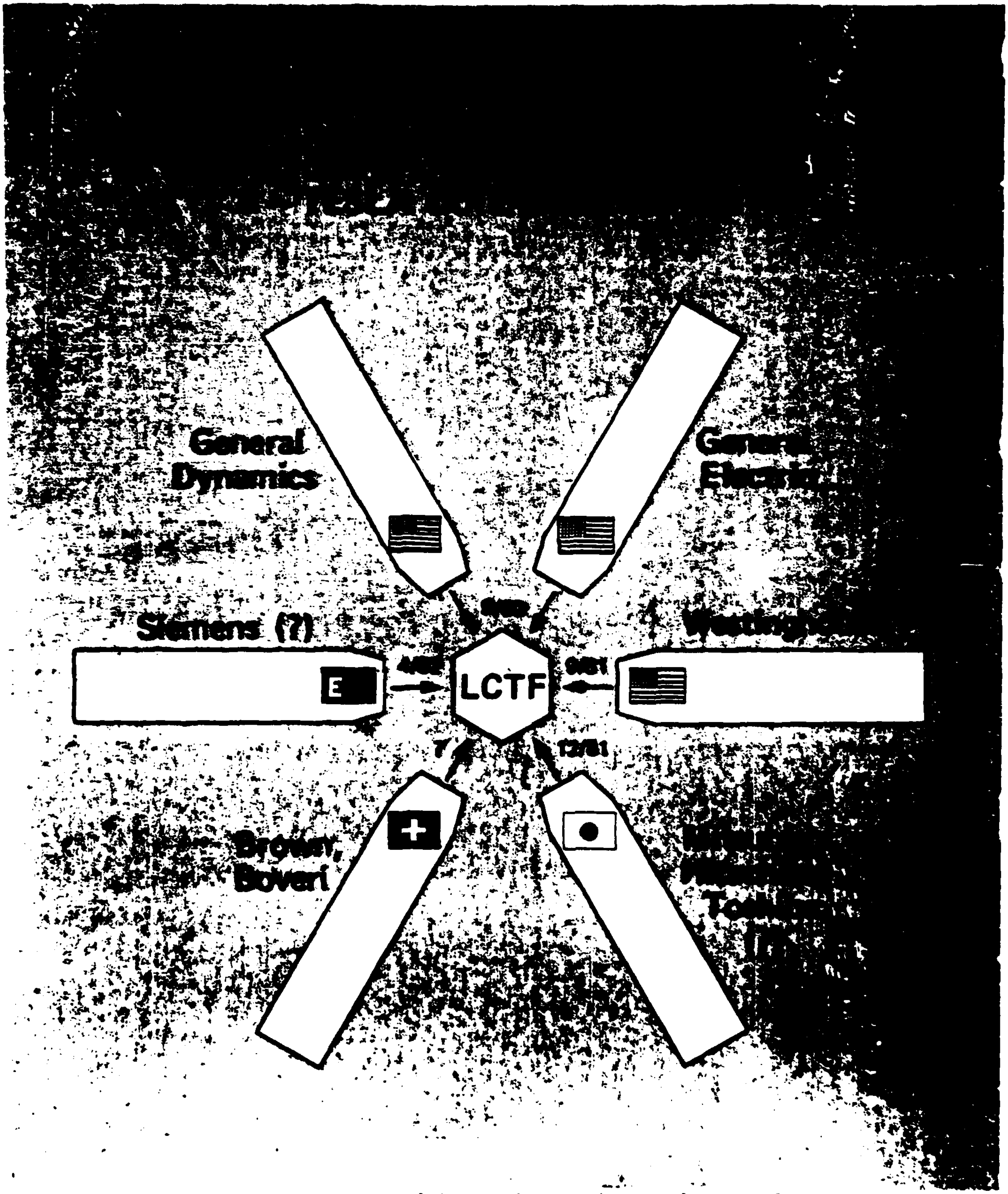
1. ETF CONCEPTUAL DESIGN
2. LCP COIL MODEL
3. LCP COIL LAYOUT
4. LCTF VACUUM TANK
5. MODEL OF 6-COIL SYSTEM
6. LCP SCHEDULE
7. 12-T COIL TEAMS
8. SPECIFICATIONS
9. OUTLINE OF 12-T COIL PROGRAM
10. CONDUCTOR AND COOLING CONCEPTS
11. MODEL COIL TEST FACILITY
12. TEST ARRANGEMENT DETAILS



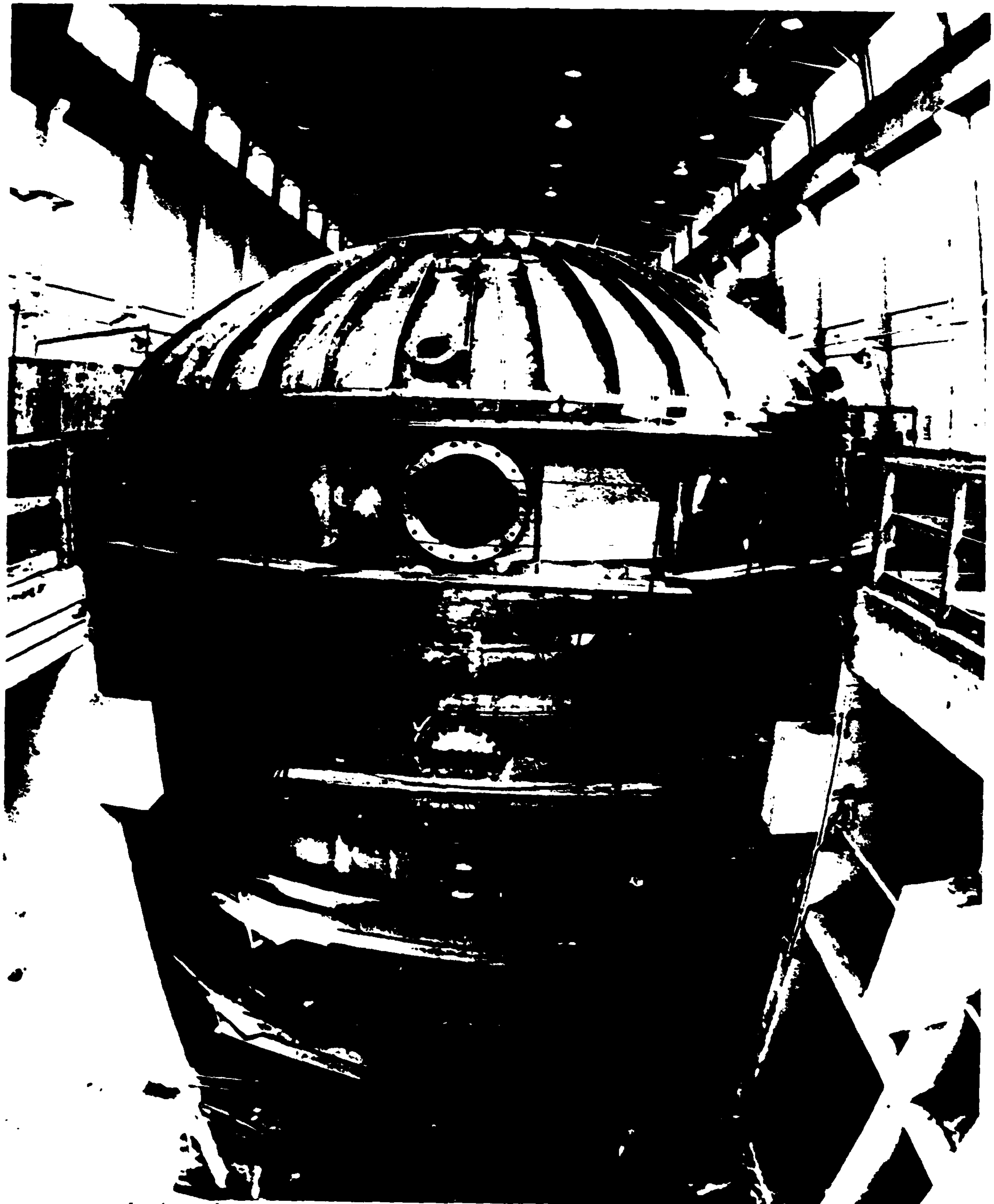
Conceptual design for the Engineering Test Facility, a tokamak fusion machine demonstrating engineering feasibility.



A full scale model of one of the six superconducting test coils for the Large Coil Program.



Plan view of the coil layout for testing the large coils.

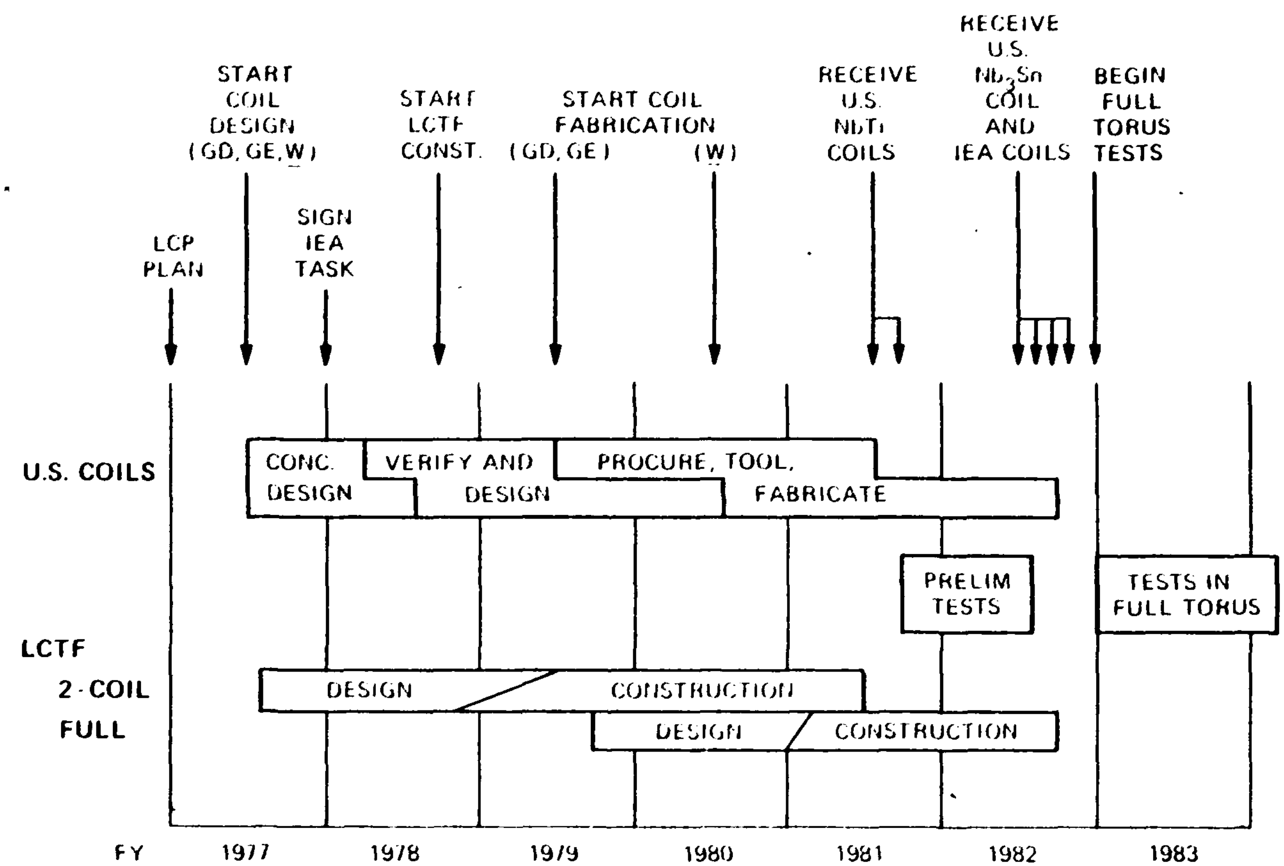


A view of the Large Coil Test Facility vacuum tank under construction.

A scale model of the six coils as they will be arranged in the test facility.

ORNL-DWG 80 2362 FED

MILESTONES AND SCHEDULE FOR THE LCP



12 T COIL TEAMS

	MANAGEMENT	COIL DESIGN	COIL FABRICATION	CONDUCTOR MANUFACTURER
(1)	GAC	GAC/MCA	MCA	MCA/UW
(2)	NML (MIT)	NML	W	AIRCO & SUPERCON
(3)	ORNL	GD/AIRCO	GD	AIRCO
(4)	ORNL	GE/IGC	GE	IGC

OUTLINE OF 12 T COIL PROGRAM

ORNL WITH GD/AIRCO AND GE/IGC

PART I : SCOPING STUDY OF 12 T TF COIL FOR ETF — GE GD Finished

PART II: (1) CONCEPTUAL DESIGN OF 12 T MODEL COIL — GE

(2) DETAILED DESIGN & VERIFICATION TESTS

(3) PROCUREMENT & FABRICATION

Negotiating New Contracts

AD-A085 974 FRANKLIN RESEARCH CENTER PHILADELPHIA PA POWER INFORM--ETC F/G 20/3
SUMMARY OF THE PROCEEDINGS OF THE SUPERCONDUCTIVITY TECHNICAL E--ETC(U)
APR 80 NASW-3219
UNCLASSIFIED PIC-ELE-SC 209/1 NL

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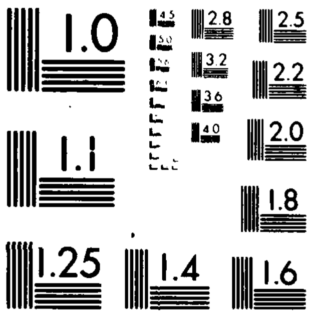


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

CONDUCTOR & COOLING CONCEPTS

	TEAM	CONDUCTOR	COOLING	RATING
(1)	GAC/MCA	NbTi Ta CABLE	PB - SUBCOOLED TO 2.3 K	10 kA
(2)	NML/W/AIRCO/SUPERCON	MF-Nb_3Sn CABLE IN CONDUIT	FF - SUPERCRITICAL, 4.2 K	15.7 kA
(3)	ORNL/GD/AIRCO	MF-Nb_3Sn MONOLITH	PB AT 4.2 K	10 kA
(4)	ORNL/GE/IGC	MF-Nb_3Sn CABLE	PB† AT 4.2 K	15 kA

† choice

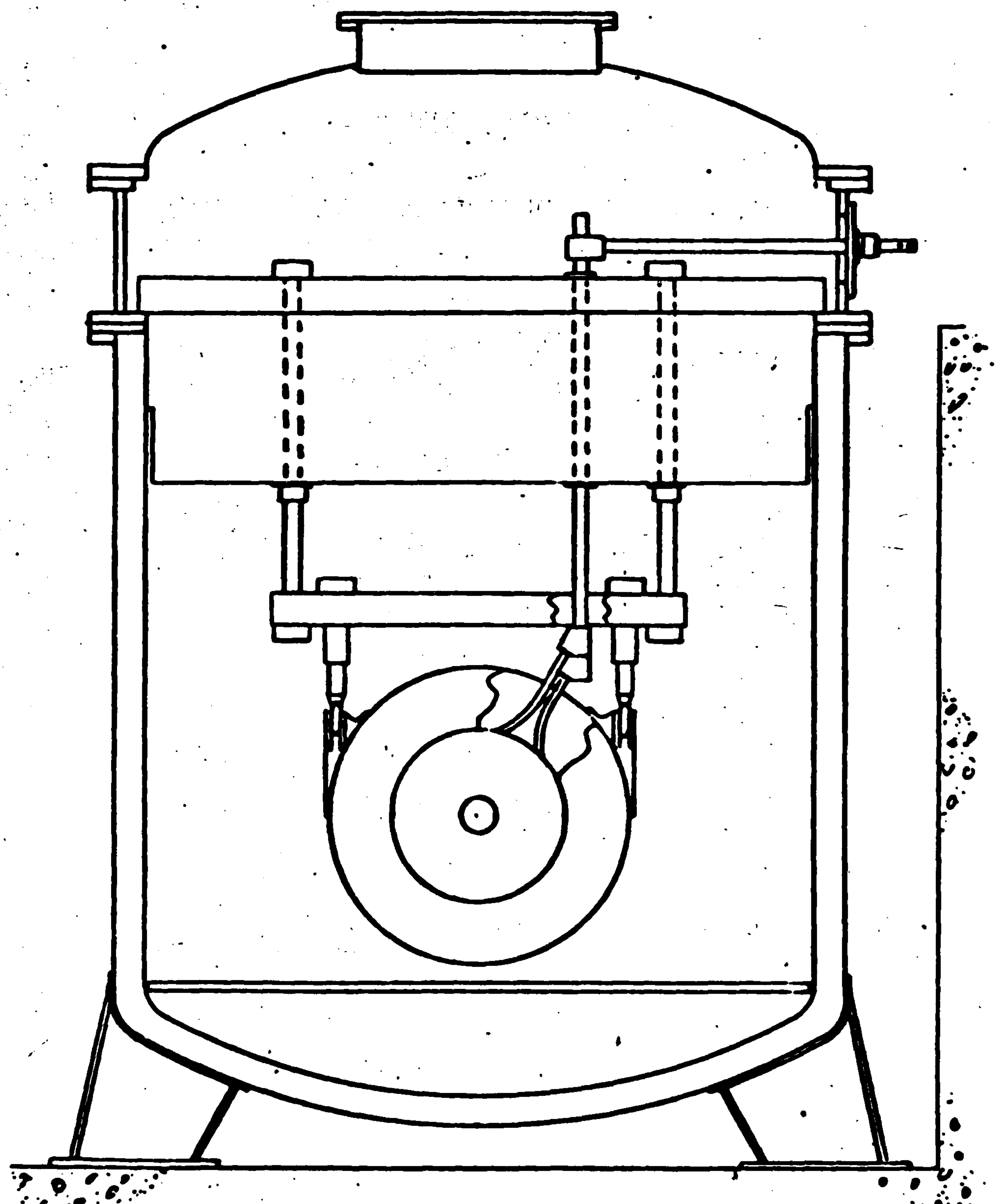
ORNL Prepared Specs (with ETF Advice)

SPECIFICATIONS (Revision 2, May 4, 1979)

TABLE I

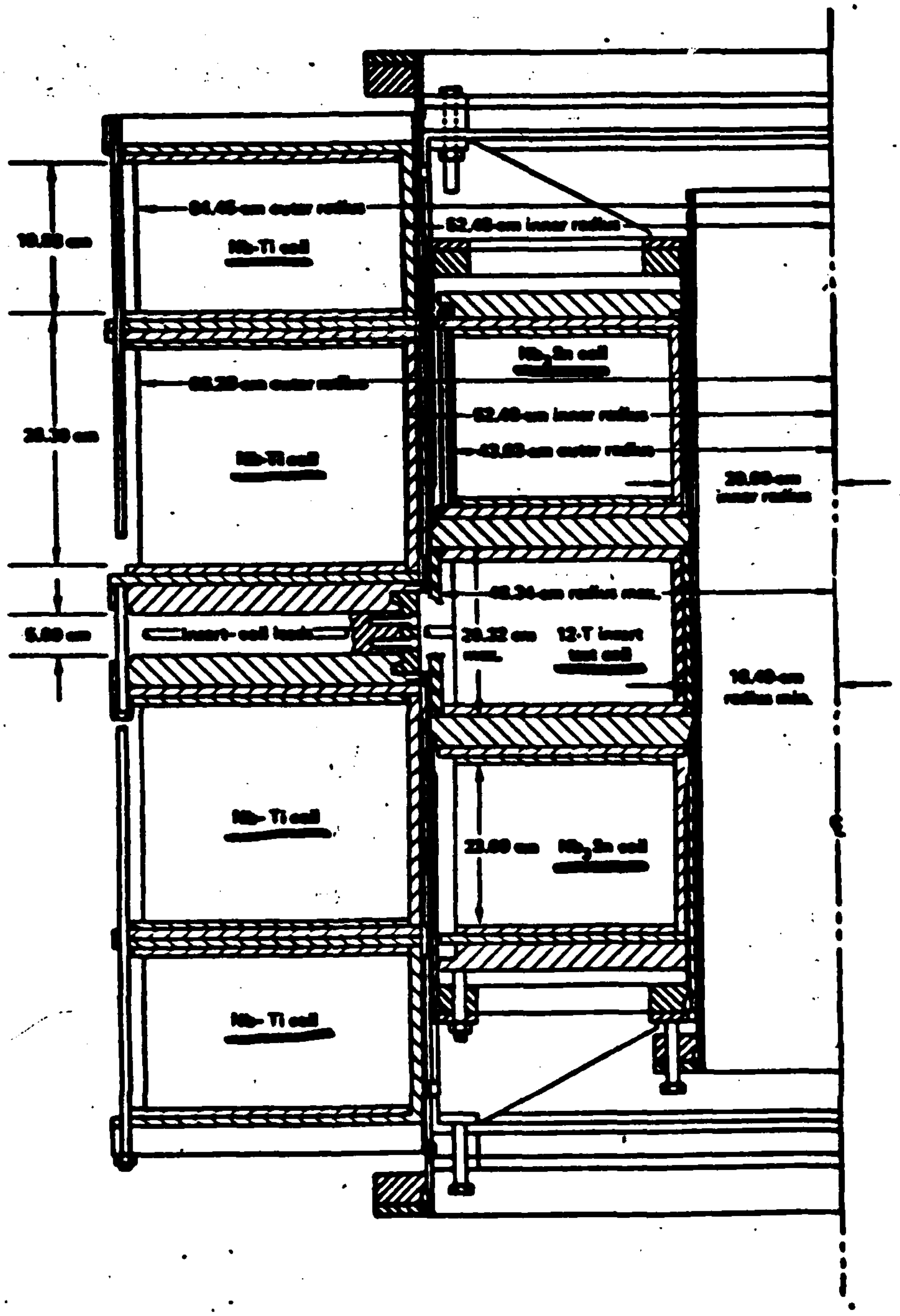
ETF TF COIL SPECIFICATIONS

1. Plasma Major Radius $\simeq$ 5 m
2. Coil Major Radius $\simeq$ 5.8 m
3. Coil Bore Size - 6 m horizontal x 10 m vertical
4. Coil Shape - Modified D-Shape
5. Number of Coils - 12
6. Field on Plasma Axis $\sim$ 5.8T
7. Peak Field at the Winding - 12T
8. Conductor - Nb_3Sn
9. Field Profile - Maximum on the center line
10. Amp Turns/Coil $\simeq$ 12 MA
11. Current Density over Winding Pack > 1700 A/cm^2
    over Conductor $\geq$ 2200 A/cm^2
12. Operating Current - 10 to 15 kA
13. Stored Energy/Coil $\sim$ 1500 MJ
14. Stability Margin - 1/2 turn length at the high field region can withstand 100 mJ/cm^3 without undergoing a quench
15. Tolerance for Pulsed Fields - Same as LCP specifications 0.15 T in 1 sec Rate ≤ 1 in 5 min.
16. Tolerance for Radiation - Same as LCP specifications (TS-14700-01 Rev. C, Par. 3.2.8, 3.2.14, 3.3.5)
17. Vacuum Topology - Bell jar with re-entrant holes
18. Plasma Disruption - 0.5 T in 10 ms



12 T HIGH FIELD TEST FACILITY
4 METER DIA. CRYOSTAT

HFTF



DIVISION OF ELECTRIC ENERGY SYSTEM'S SUPERCONDUCTIVITY PROGRAM

Presented By Russell Eaton
Dept. of Energy, Washington, DC

ABSTRACT

The Division of Electric Energy Systems of the United States Department of Energy has an integral project in superconductivity to support the development of the nations future transmission and distribution system. The development of compact, underground superconductivity transmission cables systems offers attractive alternatives to conventional cable systems for application where right-of-ways are extremely limited. Some of the concepts are being demonstrated in the 100 meter pre-prototype superconducting, flexible cable systems at the Brookhaven National Laboratories. Other important projects in superconducting power transmission are the 10 MVA generator and the superconductivity fault current limitor. A number of smaller efforts, primarily directed to materials research, are also in progress.

DEVELOPMENT OF STANDARDS FOR PRACTICAL SUPERCONDUCTORS

Presented by A. F. Clark
Thermophysical Properties Division
National Bureau of Standards
Boulder, Colorado

ABSTRACT

Practical superconductors are complex materials and the accurate determination of the parameters required for designing with them is a difficult task. Many approaches are possible for determining a given parameter and the results depend critically on which one is chosen. The National Bureau of Standards is now working in conjunction with the manufacturers and users of superconducting wires to arrive at a set of voluntary standards for making and reporting measurements on these materials. The program involves the preparation of standard definitions, investigation of current measurement practices, experimental determination of the effect of various apparatus parameters, and development of standard test methods. Results from the program and current research will be summarized.

STANDARDS FOR PRACTICAL SUPERCONDUCTING MATERIALS

GOAL

Adoption of Voluntary Standards for the Characterization of Practical Superconducting Materials

Standards for Practical Superconducting Materials

- A cooperative program funded by:

  National Bureau of Standards

  Department of Energy

  Division of Energy Storage

  Office of Fusion Energy

  Division of High Energy Physics

  Division of Magnetohydrodynamics

  (thru Francis Bitter National Magnet Laboratory)

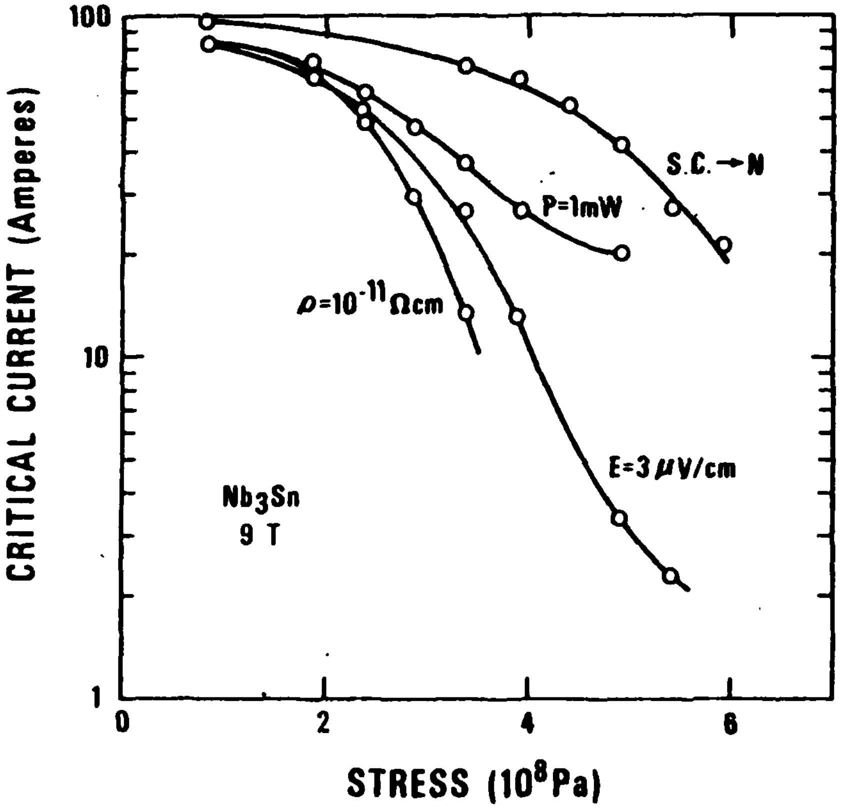
  USAF Aeropropulsion Laboratory

- Research performed at NBS and by industrial subcontractors

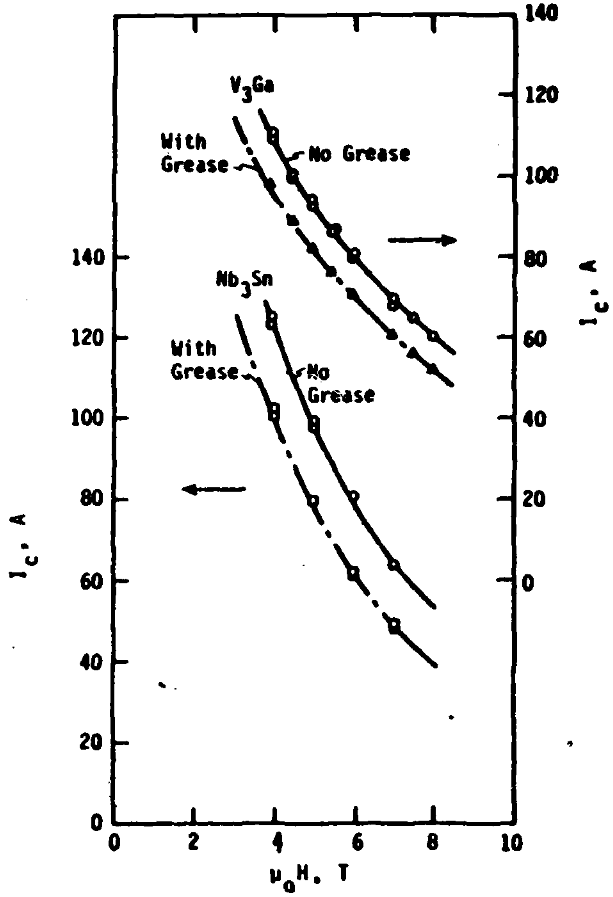
Why are Standards needed: an example

Critical Current

Definition



Technique



Benefits of Standards

- **Improved precision in specifications**
- **Better characterization of products**
- **Uniform, reliable design data**
- **Broader and more consistent RFP responses**
- **Improved research capabilities**
- **Calibration services and reference materials**

Reduced Costs

&

Greater Reliability

SUPERCONDUCTING PARAMETERS

1. Critical Current, I_c
2. Transient Losses, e.c., hysteresis, ρ
3. Matrix Properties, ρ, λ, stabilization
4. Critical Temperature, T_c
5. Critical Field, H_c

OBJECTIVES

DEFINE PARAMETERS

- Survey literature for historical definitions
- Assess current practical uses
- Prepare and distribute interim definitions
- Reevaluate after test development

DEVELOP TEST PROCEDURES

- Survey literature for possible methods
- Assess current test practices
- Select and develop test methods
- Organize round robin testing and feedback
- Coördinate adoption and publication

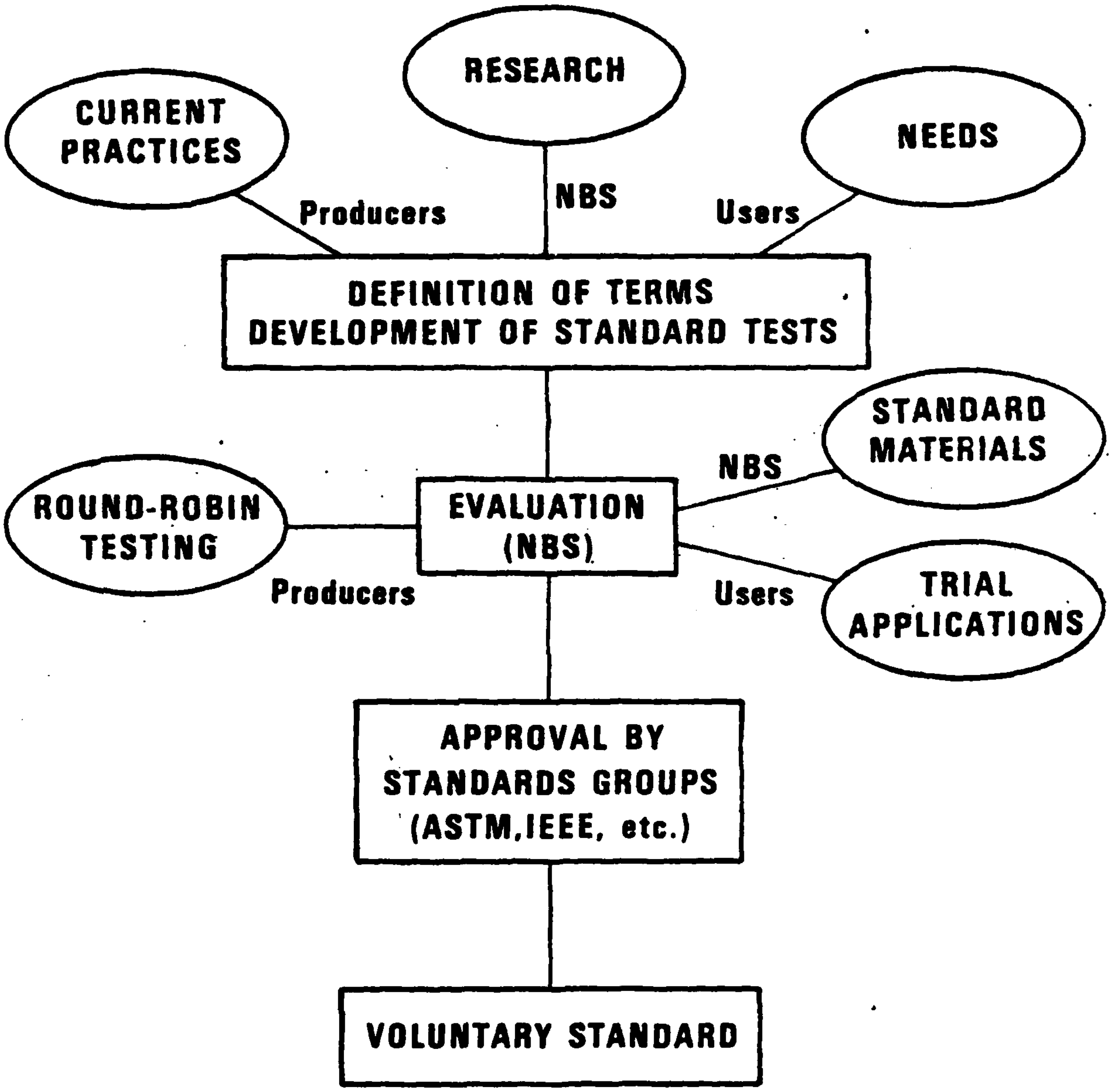
OBJECTIVES

PREPARE STANDARD MATERIALS

- Select and prepare variety of materials
- Characterize materials during test development
- Include materials in round robin testing
- Encourage adoption of standard reference materials

COORDINATE STANDARDS

- Survey material and device manufacturers
- Include producers and users in test development
- Distribute proposed standards and test results for evaluation
- Coordinate implementation of voluntary standards


RESEARCH
CURRENT PRACTICES
NEEDS
Producers
NBS
Users
DEFINITION OF TERMS
DEVELOPMENT OF STANDARD TESTS
STANDARD MATERIALS
NBS
ROUND-ROBIN TESTING
EVALUATION (NBS)
Producers
Users
TRIAL APPLICATIONS
APPROVAL BY STANDARDS GROUPS (ASTM,IEEE, etc.)
VOLUNTARY STANDARD

Results From The Program

Technical

- **Interim definitions**
- **ASTM subcommittee**
- **National survey of techniques**

Experimental

- **Critical current studies**
- **Critical temperature technique comparisons**
- **AC loss technique comparisons**

Contracts

- **Airco - current ripple, field angle**
- **IGC - self field, matrix RRR**
- **MCA - current transfer**
- **Supercon - I_c vs. sample configuration**

Interim Definitions Published for Comment

Published in Cryogenics

- **Fundamental states and flux phenomena**
- **Critical parameters**
- **Fabrication, stabilization and transient losses**
- **Josephson phenomena**

Supporting Superconductor Research at NBS - Boulder

(Funding by: NBS, Navy, INCRA, DOE, LASL)

- **Stress and fatigue in wires**
- **Stress and fatigue in coils**
- **Training of coils**
- **Stabilizing metals - Cu, Al**
- **New high-field superconductors**
- **In-situ processing**
- **Transfer length**
- **Thermal expansion**
- **Elastic properties**
- **Thermal conductivity**
- **Magnetic properties**

CASTING OF DENDRITIC Cu-Nb ALLOYS FOR SUPERCONDUCTING WIRE

Presented By D. K. Finnemore
Ames Laboratory-USDOE
Department of Physics
Iowa State University
Ames, Iowa

ABSTRACT

Consumable electrode arc casting techniques have been developed for the preparation of large billets of dendritic Cu-Nb alloys which are suitable for the fabrication of multifilamentary superconducting wire. The dendrite structure is somewhat more coarse than chill cast material but metallographic and chemical analyses show acceptably small radial and longitudinal segregation. The billets can be drawn to wire with no intermediate anneals. Both external diffusion after tin plating and internal diffusion of wire with a tin core can be used to transform the Nb filaments to Nb_3Sn. The arc cast wire displays Jc values equivalent to previously reported values on in-situ wire at high fields but somewhat lower values at low fields.

PROJECT

I. GOAL

A) SUPERCONDUCTING WIRE FOR LARGE SCALE MAGNETS

1) 8-14 TESLA

2) LOW COST

3) STRAIN TOLERANT (DUCTILE FLEXIBLE)

4) LOW REACTION TEMPERATURE

II. IDEA

A) CONTINUOUS FILAMENTS ARE NOT NEEDED IF THE FILAMENTS ARE:

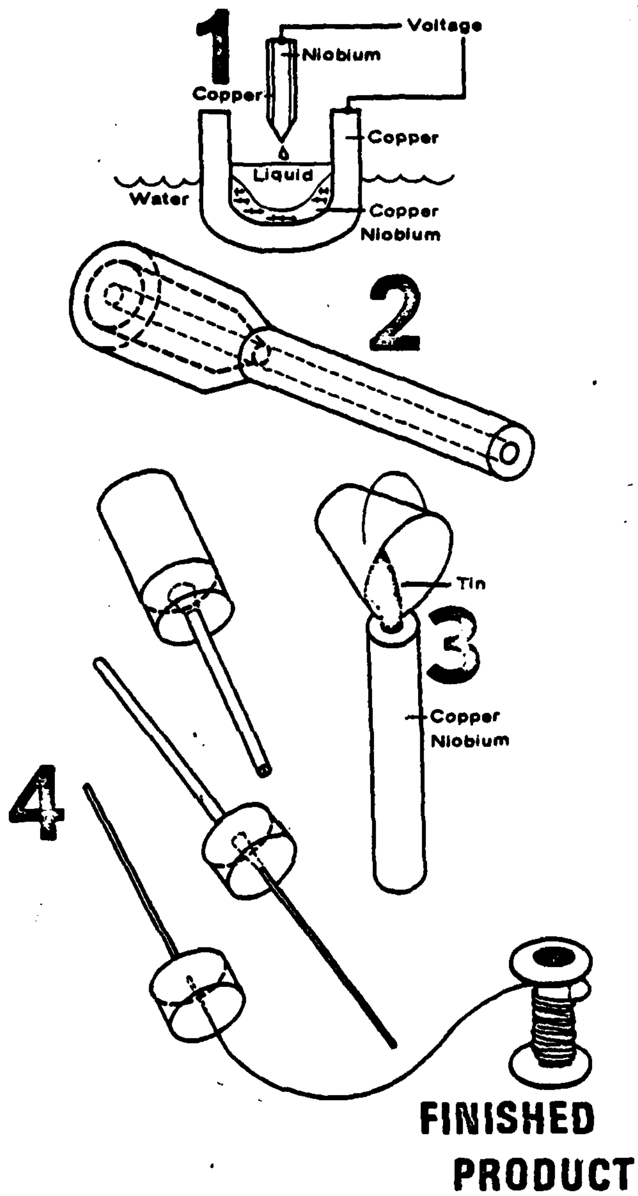
1) LONG ENOUGH

2) THIN ENOUGH

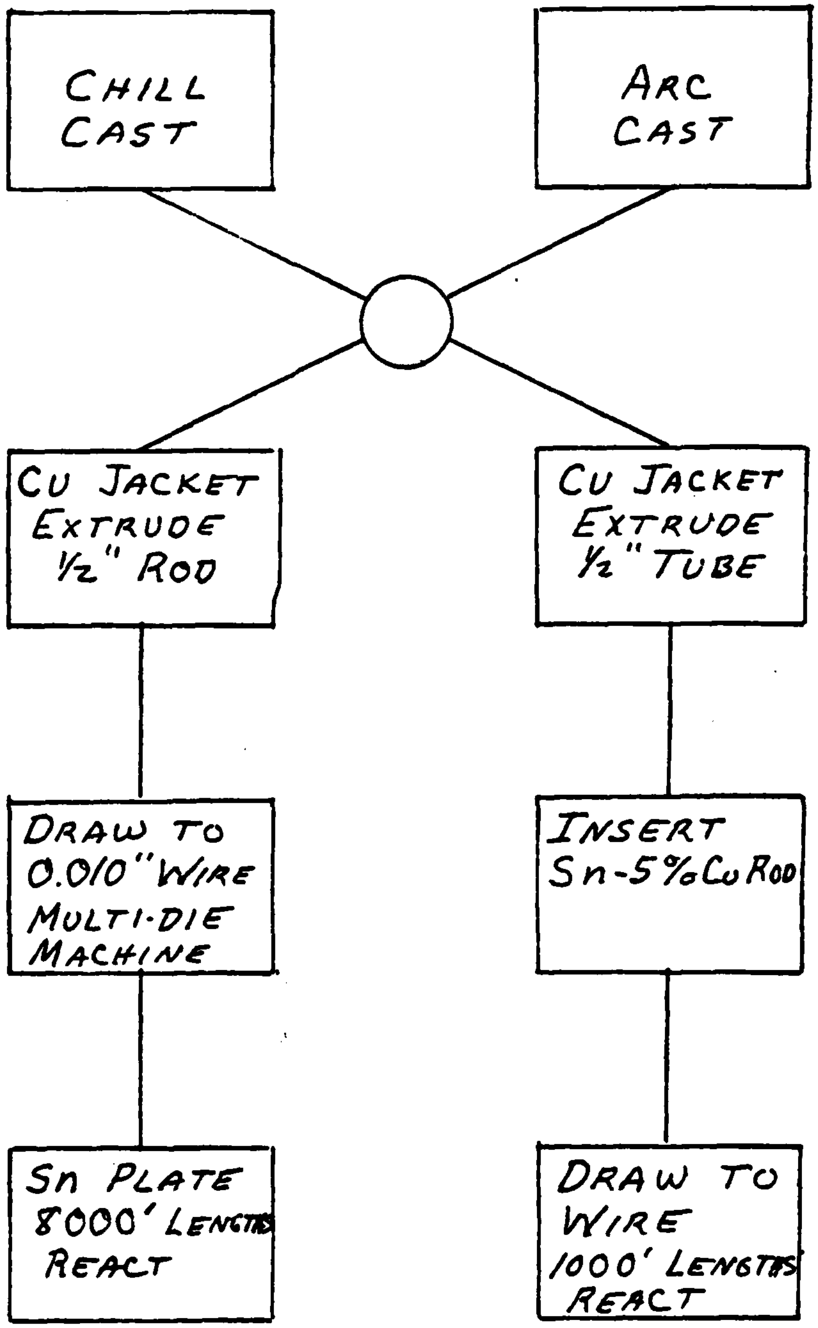
3) HOMOGENEOUSLY SPACED ENOUGH

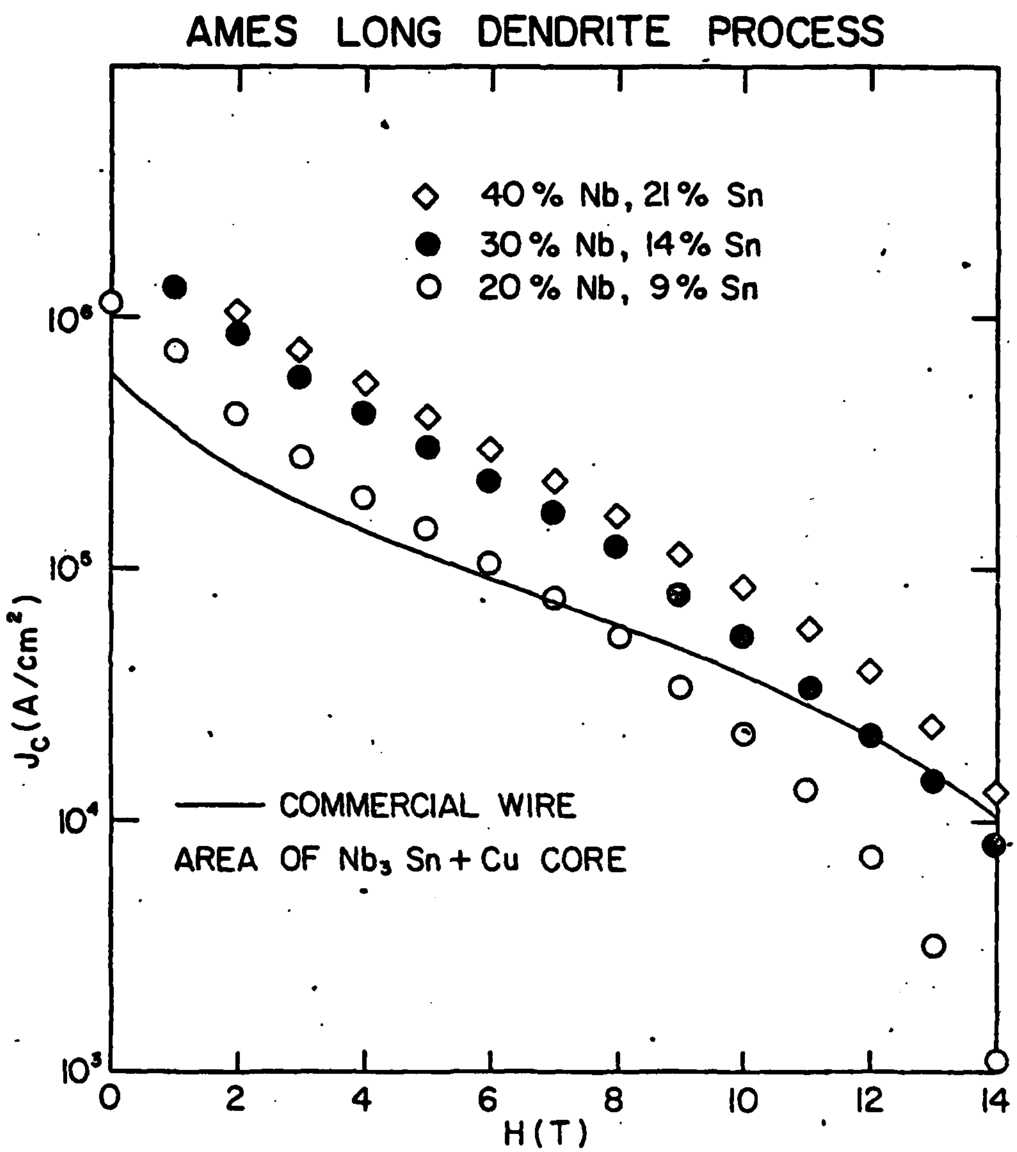
B) PREPARE FILAMENTS VIA DENDITE GROWTH

Ames process for superconducting wire.

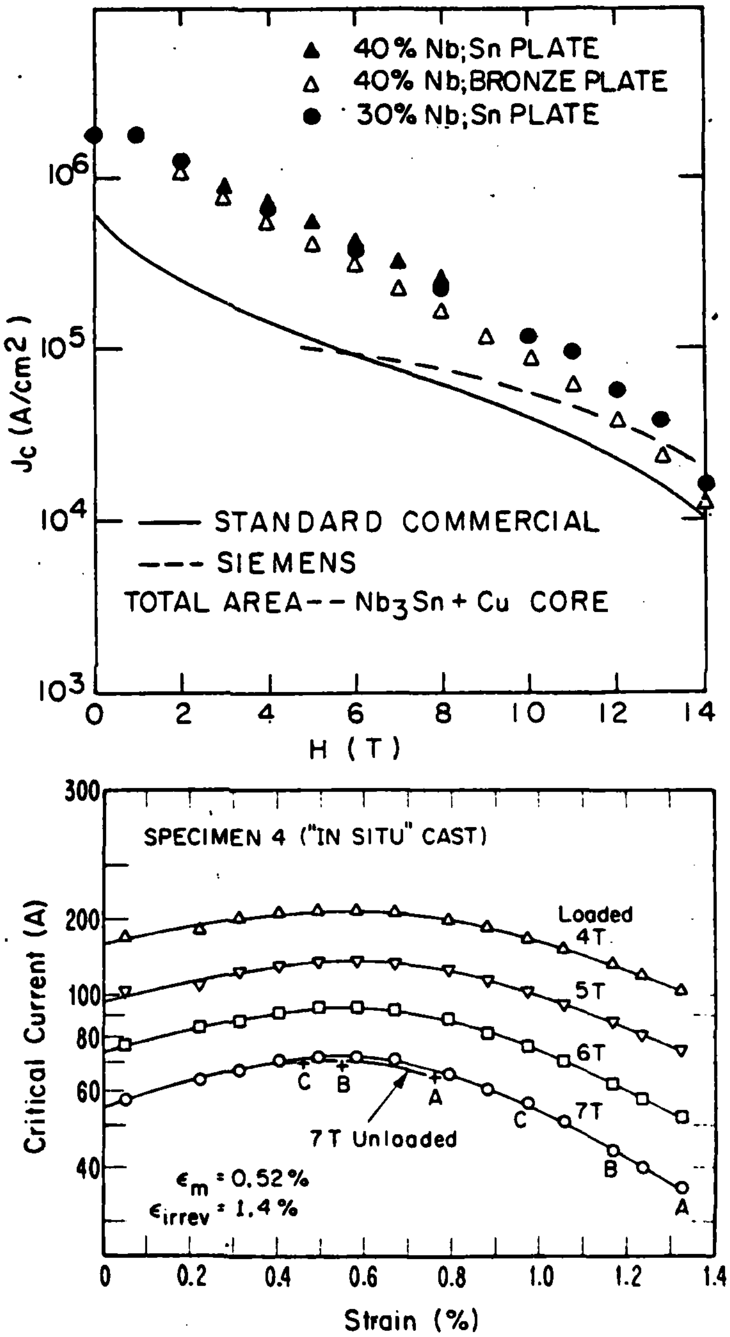


Sequential steps for the Ames process.




AMES LONG DENDRITE PROCESS
40 % Nb, 21 % Sn
30 % Nb, 14 % Sn
20 % Nb, 9 % Sn
COMMERCIAL WIRE
AREA OF Nb₃ Sn + Cu CORE
J_c (A/cm²)
10^6
10^5
10^4
10^3
0
2
4
6
8
10
12
14
H(T)

CRITICAL CURRENT AND STRAIN TOLERANCE



VI. SPECIAL FEATURES

A. EASE OF FABRICATION

B. 500°C REACTION TEMPERATURE

C. REPRODUCIBLE RESULTS

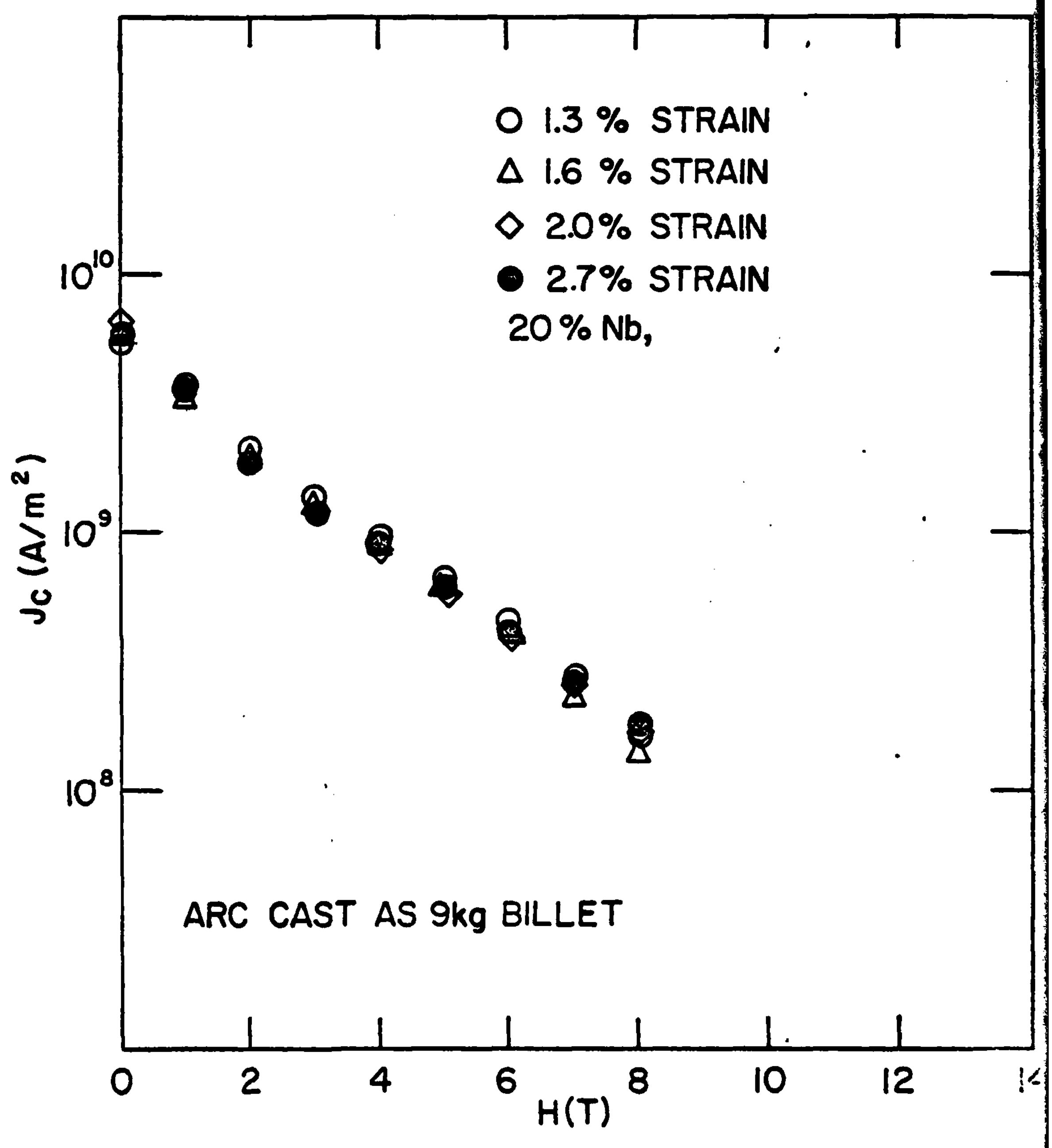
D. WIDE RANGE OF PARAMETERS FOR DESIGN TRADE-OFFS

E. HIGH STRENGTH

F. STRAIN TOLERANT

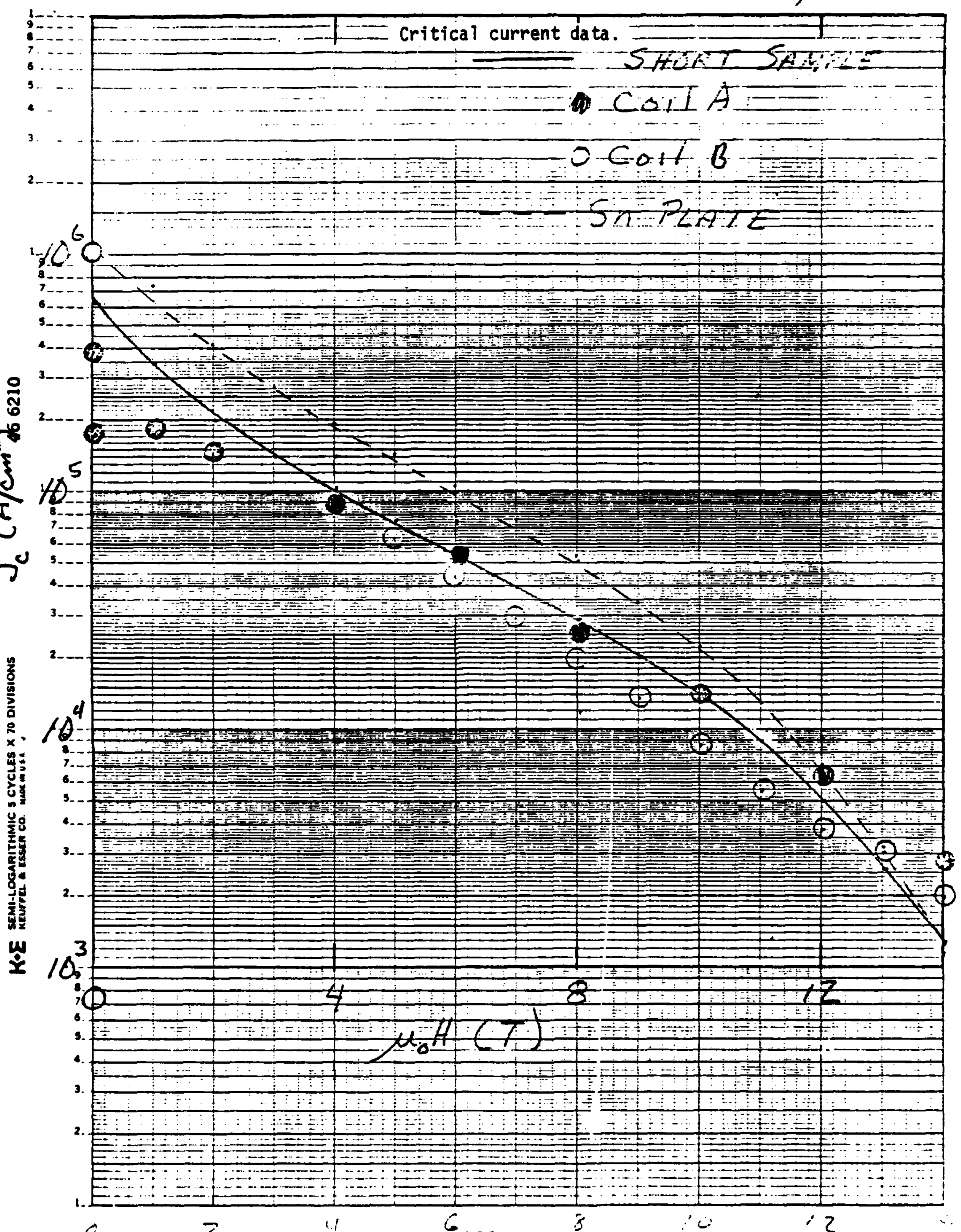
G. DRAW SHORT LENGTHS TO 0.015 CM DIAM. WITH NO ANNEALS

H. SOLDERS LIKE CU WIRE



1.3 % STRAIN
1.6 % STRAIN
2.0% STRAIN
2.7% STRAIN
20 % Nb,
10^{10}
10^{9}
10^{8}
J_c (A/m^2)
ARC CAST AS 9kg BILLET
0
2
4
6
8
10
12
14
H(T)

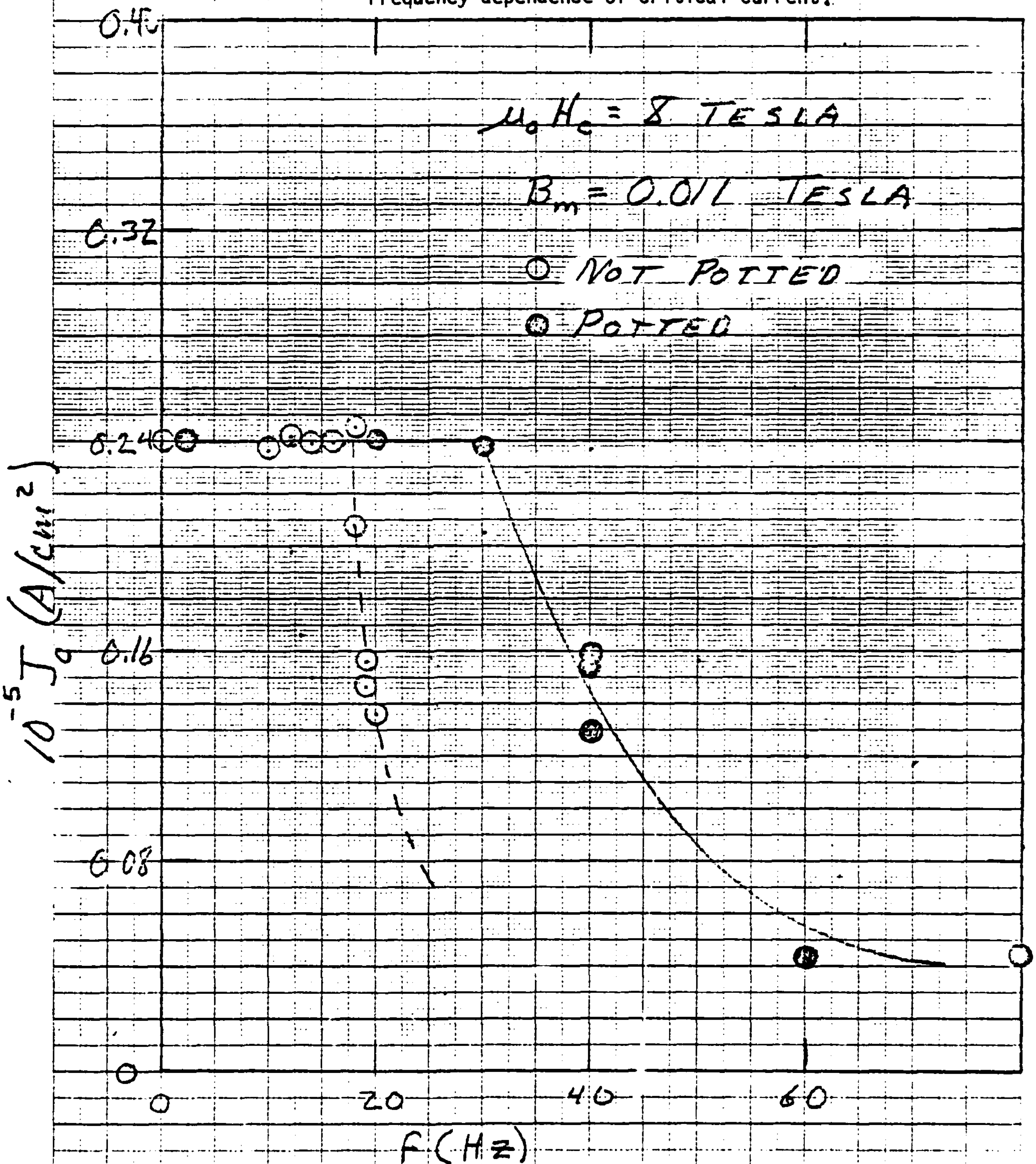
Fig 1



Critical current data.
SHORT SAMPLE
Coil A
Coil B
Sn PLATE
J_c (A/cm^2)
10^6
10^5
10^4
10^3
$\mu_0 H$ (T)
4
8
12
0
2
4
6
8
10
12
K·E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6210

Fig. 2

Frequency dependence of critical current.



REVIEW OF RECENT DEVELOPMENTS OF
MULTIFILAMENTARY Nb_3Sn BY
"IN SITU" AND COLD
POWDER METALLURGY PROCESSES*

Presented by S. Foner
Francis Bitter National Magnet
Laboratory and Plasma
Fusion Center
Massachusetts Institute of Technology
Cambridge, Massachusetts

ABSTRACT

The development of both the "In Situ" and cold powder metallurgy processes for multifilamentary high field superconducting materials is reviewed. Both materials show overall critical current densities of $J_c \geq 10^4$ A/cm^2 at 14 tesla and both show improved mechanical properties over conventional multifilamentary materials. The processes produce submicron fibres of Nb_3Sn (or V_3Ga) in a ductile Cu matrix resulting in wires which are promising as alternatives to conventional continuous fibre multifilamentary superconducting materials.

During the last two years we have explored two processes for the fabrication of multifilamentary high field superconducting materials: the "In Situ" process and the cold powder metallurgy (P/M) process. Both processes have been developed to the point where high critical currents are achieved at high fields. Furthermore, both processes show improved mechanical properties over conventional multifilamentary materials. In this paper we summarize some of the characteristics of our materials fabricated by each process.

*Presented at the 8th Symposium on Energy Problems of Fusion Research, Nov. 13-16, 1979 in San Francisco, California; to be published by IEEE.

FIGURES

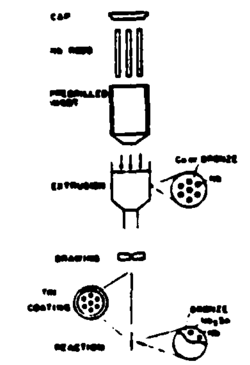


Fig. 1. Schematic of conventional continuous multifilamentary Nb_3Sn wire fabrication.

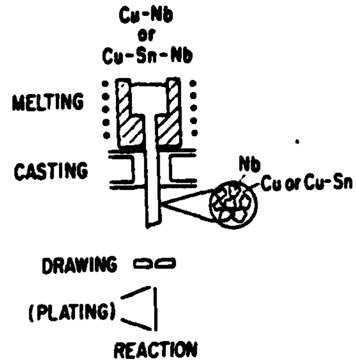


Fig. 2. Processing of "In Situ" multifilamentary superconductors proceeds from melting to the final stage of reaction to form Nb_3Sn. (After Ref. 2)

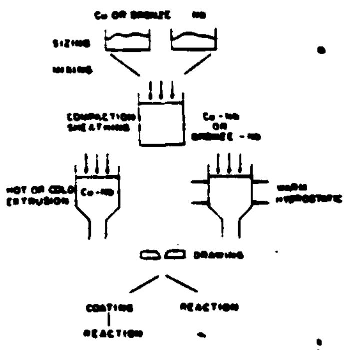


Fig. 3. Schematic of cold powder metallurgy multifilamentary Cu-Nb-Sn process.

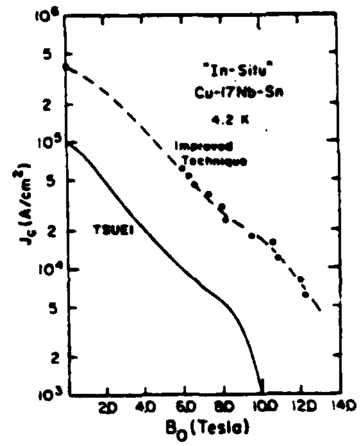


Fig. 4. Critical current density J_c (using total cross-sectional area of the wire) versus applied field B_0 at 4.2 K. Results of Tsuei (Ref. 19) are compared with present "In Situ" material: 0.25 mm-diam wire, 17 wt% Nb-7 wt% Sn annealed for 3 days at [illegible]°C. (After Ref. 6.)

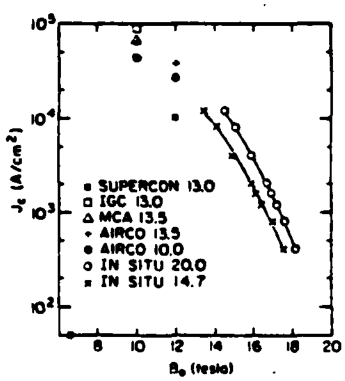


Fig. 5. Overall critical current density J_c versus applied field B_0 for "In Situ" Cu-30 wt% Nb-x wt% Sn wires compared to published results for bronze technique obtained at lower B_0. (After Ref. 5.)

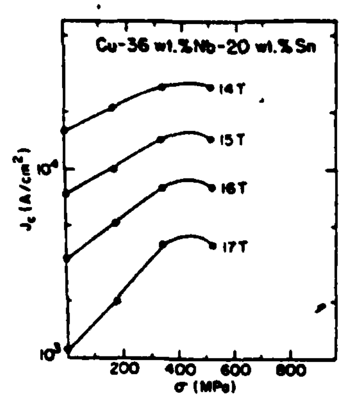


Fig. 6. Overall current density, J_c, versus stress, σ, for a Cu-36 wt% Nb-14.7 wt% Sn wire. The applied transverse field, B_0, is indicated for each curve. (After Ref. 6.)

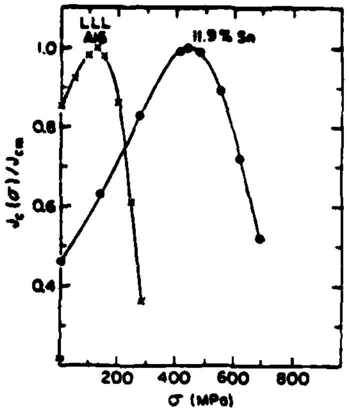


Fig. 7. Normalized $J_c = J_c(\sigma)/J_{cm}$, where J_{cm} is the maximum critical current density under stress, as a function of stress σ at 14 T for [illegible] "In Situ" wires. (After Ref. 6.)

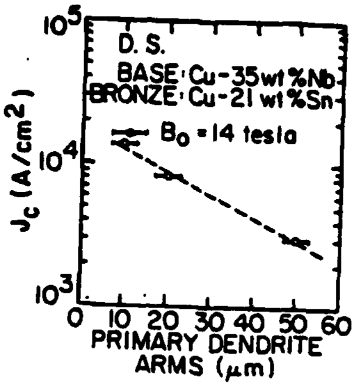


Fig. 8. Overall current density J_c at 14 T as a function of the primary dendrite arm size of the original alloy [illegible] All had the same composition and same heat treatment (1 day at [illegible]). The closed circle is for a [illegible] specimen. (After Ref. 11.)

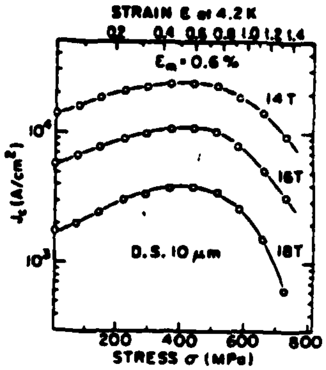


Fig. 9. Overall critical current density, J_c, versus stress and strain at 4.2 K for a 10 μm dendrite size directionally solidified material. The base alloy was Cu-35 wt % Nb. (After Ref. 11.)

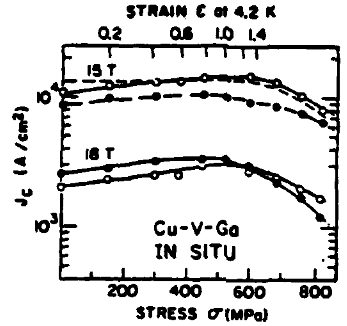


Fig. 10. Overall critical current density J_c at 4.2 K versus stress σ at fixed fields for Cu-31.3 at % V [illegible] (After Ref. 12.)

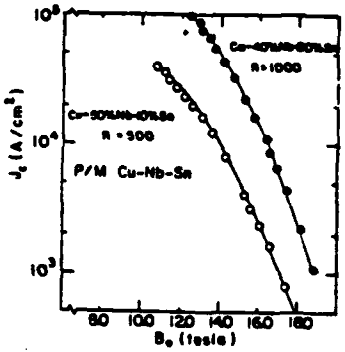


Fig. 11. Overall critical current density J_c versus applied field B_0 for representative Cu-Nb-Sn materials produced by the [illegible] process with [illegible] Nb powder. [illegible] (After Ref. 15.)

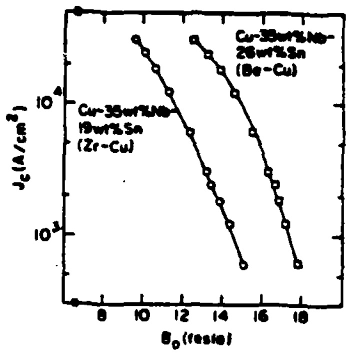


Fig. 12. Overall critical current density J_c versus applied field B_0 for cold powder metallurgy (P/M) processed Cu-Nb-Sn materials at 4.2 K. [illegible] (After Ref. 16.)

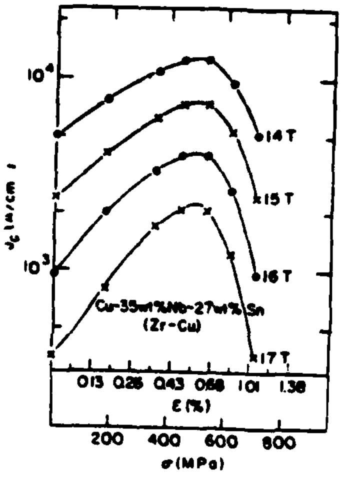


Fig. 13. Overall critical current density J_c versus stress σ at 4.2 K and fixed fields for (P/M) processed Cu-35 wt % Nb-27 wt % Sn fabricated with Zr-Cu outer jacket. The strain ε at 4.2 K is also shown for corresponding stress. (After Ref. 16.)

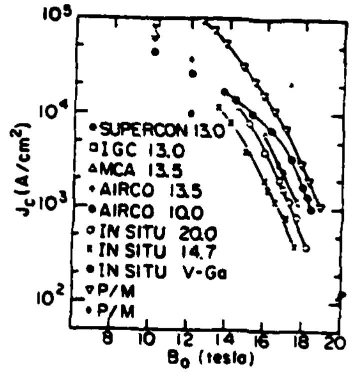


Fig. 14. Comparison of overall critical current density vs applied field B_0 for commercial, "In Situ" and cold powder metallurgy processed wires.

SUPERCONDUCTING MAGNET FACILITY AT NRL

Presented by Reid Clement
Naval Research Laboratory
Washington, D. C.

ABSTRACT

For economic reasons, NRL has decided to convert its 30-year-old High Magnetic Field Facility from exclusive use of water-cooled magnets to exclusive use of superconducting magnets. Existing and (previously) planned water-cooled magnet capability will be, to a major extent, duplicated by superconducting magnets already on hand plus ones whose purchase is planned. A significant technical development program has been required to adapt "laboratory" superconducting magnets to effective and reliable "facility" use.

ECONOMICS OF WATER-COOLED MAGNETS

- LIMITED MAGNET LIFE [200 TO 400 HOURS]
- LABOR AND PARTS FOR REPLACEMENT
- TECHNICIAN LABOR FOR SYSTEM OPERATION
- ELECTRICITY COSTS [to NRL] - MAINLY "DEMAND" PROBLEM
- "ONE-AT-A-TIME" USE
- INCREASING MAINTENANCE BECAUSE OF SYSTEM AGE [STARTED 1950]

ECONOMICS OF SUPERCONDUCTING MAGNETS [WITH LIQUEFIER]

- INFINITE (?) MAGNET LIFE
- USER [RESEARCHER] OPERATION
- LOW ELECTRICITY COSTS - REDUCED "DEMAND" - ENERGY USE SAME
- SIMULTANEOUS USE OF SEVERAL MAGNETS
- MINIMAL MAINTENANCE
- BONUS - LIQUEFACTION OF OTHER NRL LIQUID HELIUM REQUIREMENTS

PRESENT AND PLANNED WATER-COOLED MAGNET CAPABILITY

RT BORE (in)	MAX FIELD (Tesla)	MIN SWEEP TIME (Minutes)
4.25	0-12	3.5
2.50	0-15	3.5
1.25	0-19	3.5
[1.20]*	[0-22+]	?

* PLANNED HYBRID

PRESENT AND PLANNED SUPERCONDUCTING MAGNET CAPABILITY

2.50	-0.7 to +14.5	30
10.75	0 to + 6.8	?
[2.50]*	[-15 to +15]	[15]
[1.20]**	[- ? to +22+]	[?]

* PLANNED DUPLEX

** PLANNED DUAL, REPLACES HYBRID, USES 10.75", 6.8T MAGNET

ADAPTING "LABORATORY" SC MAGNETS TO "FACILITY" USE

- CLOSED CYCLE COOLING - CHOICE OF DEWAR CONFIGURATION
- INEXPERIENCED USERS - AUTOMATION & SIMPLIFICATION OF OPERATION
- "QUENCHES" BAD FOR CLOSED CYCLE COOLING - AUTOMATIC QUENCH CONTROL
- RELIABILITY OF LONG TERM OPERATION - LN_2 CONTROL
- GENERAL CRYOGENIC "HOUSEKEEPING"
- FIELD MEASUREMENT & ANALOGUE SIGNAL - UNDER STUDY

AIRBORNE SUPERCONDUCTOR APPLICATIONS

Presented by C. E. Oberly
Air Force Wright Aeronautical Laboratories
Wright-Patterson AFB
Dayton, Ohio

ABSTRACT

Air Force applications of superconductivity include AC synchronous generators, magnets for MHD generators and inductive energy storage devices for high power systems (many megawatts). Emphasis in recent years has been placed on development of manufacturing methods for Nb_3Sn, unique cooling concepts and detailed structural analysis. These fundamental improvements in magnet design details will culminate in the testing of a compact MHD magnet, a 20 megawatt generator and repetitive pulse 20 kilojoule energy storage coils over the next couple of years. The next generation of high power superconducting machinery for airborne applications will incorporate Nb_3Sn and advanced cooling concepts including high thermal conductivity coating and potting materials.

HIGH PRESSURE SYNTHESIS PROGRAM
AT BENET WEAPONS LABORATORY
WATERVLIET ARSENAL

Presented by Clarke G. Homan
U.S. Army Armament Research & Development Command
Materials Engineering Section
Research Branch, BWL, LCWSL
Watervliet Arsenal

ABSTRACT

Study of materials produced by high pressure technology suggests that potentially useful physical properties may be obtained, eg., semiconducting materials such as CdS, when pressure quenched at rates above 10^6 bars/sec at ambient temperatures; yield static magnetic moment vs. field behavior similar to typical type II superconductors at temperatures above 70K.

The program to investigate the possibility of high temperature superconductivity on these materials will be discussed.

Other aspects of Benet's superconductivity materials program including hydrogen metallization and $Pd_x M_{1-x}$ H system will be discussed.

APPLICATIONS OF HIGH T_C SUPERCONDUCTORS TO U.S. ARMY NEEDS

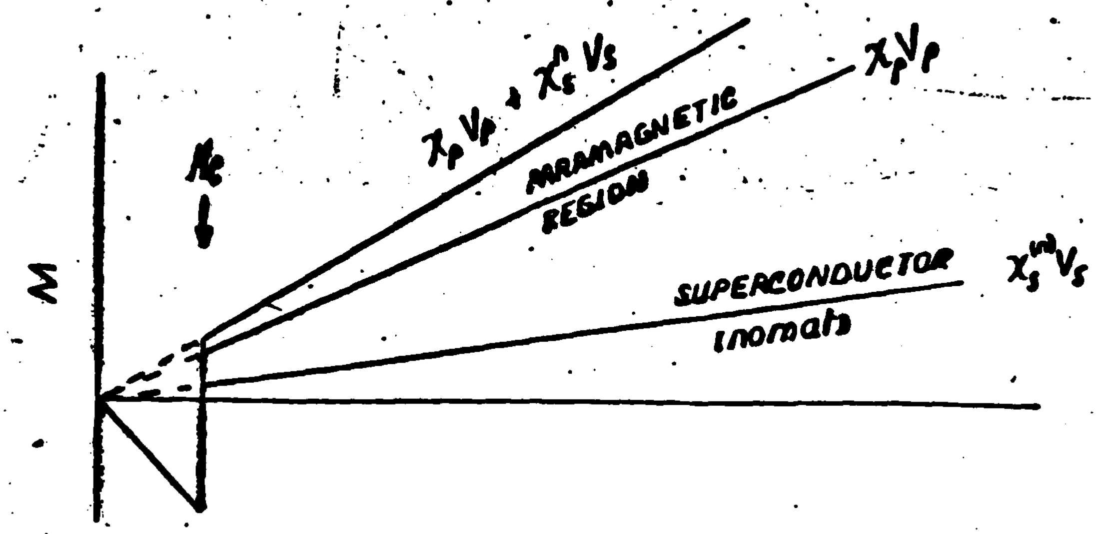
1. Power Transmission.
2. Power Generation.
3. Communications.
4. Information Processing.
5. Mass Drivers (Electromagnetically Launched Projectiles).

BENET LAB, ARRADCOM, WATERVLIET ARSENAL PROGRAM ON HIGH T_C

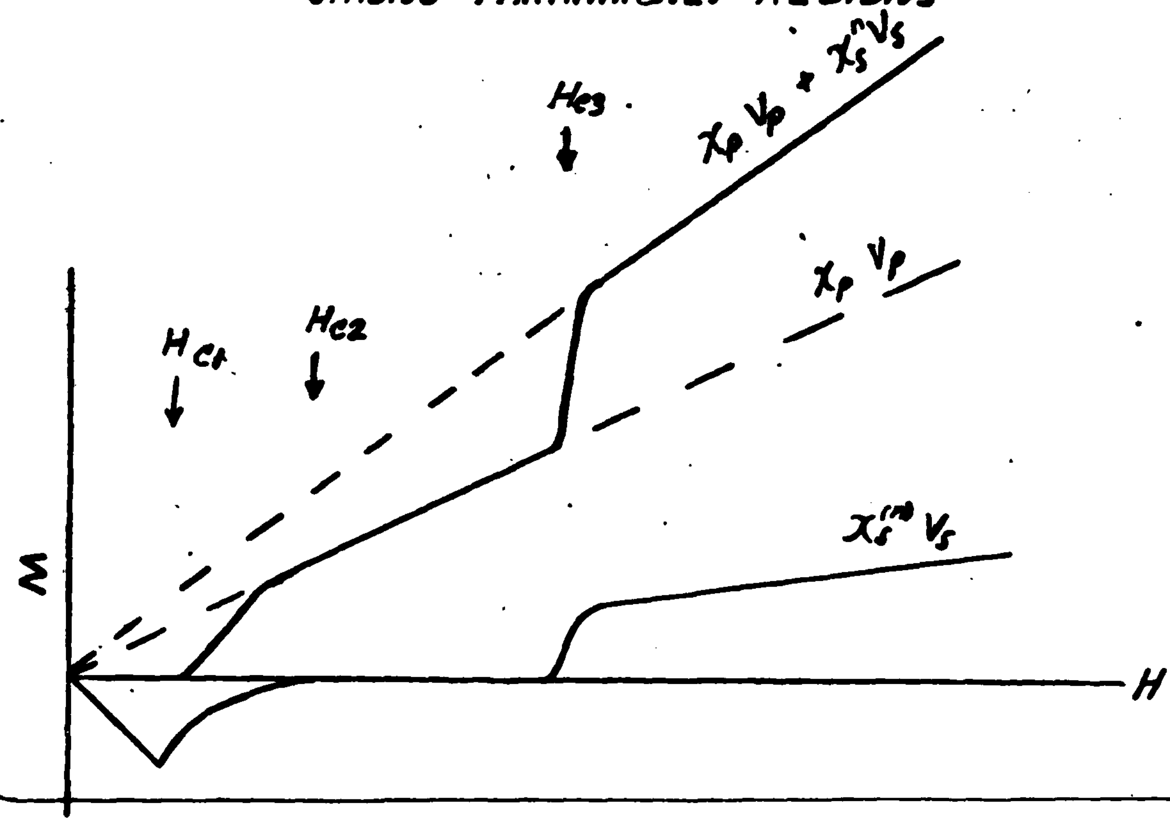
SUPERCONDUCTING MATERIALS

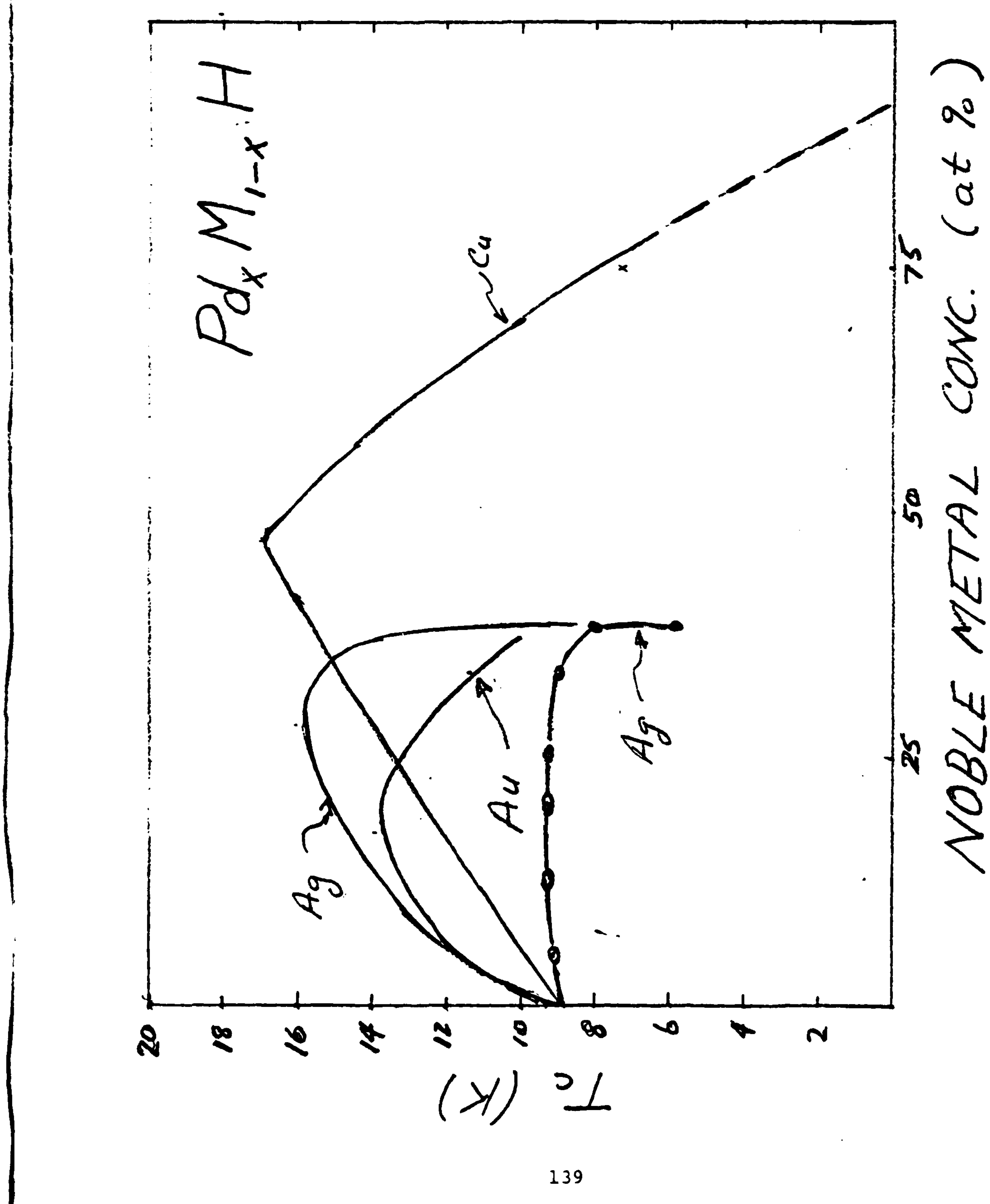
ACTUAL SUPERCONDUCTORS	PROBABLE SUPERCONDUCTORS	POSSIBLE SUPERCONDUCTORS
$T_C < 30$ K	$T_C < 200$ K	$T_C < 300$ K
PRESSURE SYNTHETIZED	PRESSURE QUENCHED COMPOUNDS	PRESSURE FORMED
$Pd_x M_{1-x} H$	CdS, Cu Cl, In Sb	Metallic H (H_2)
CVD SYNTHETIZED		
A15 Filaments		

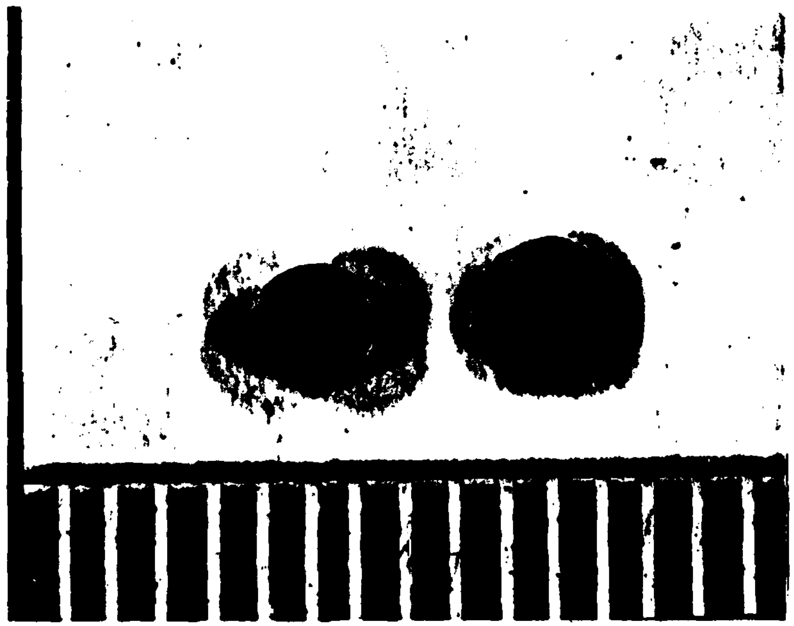
CASE I - TYPE I SUPERCONDUCTOR AND STRONG PARAMAGNETIC REGIONS



CASE II - TYPE II SUPERCONDUCTOR AND STRONG PARAMAGNET REGIONS

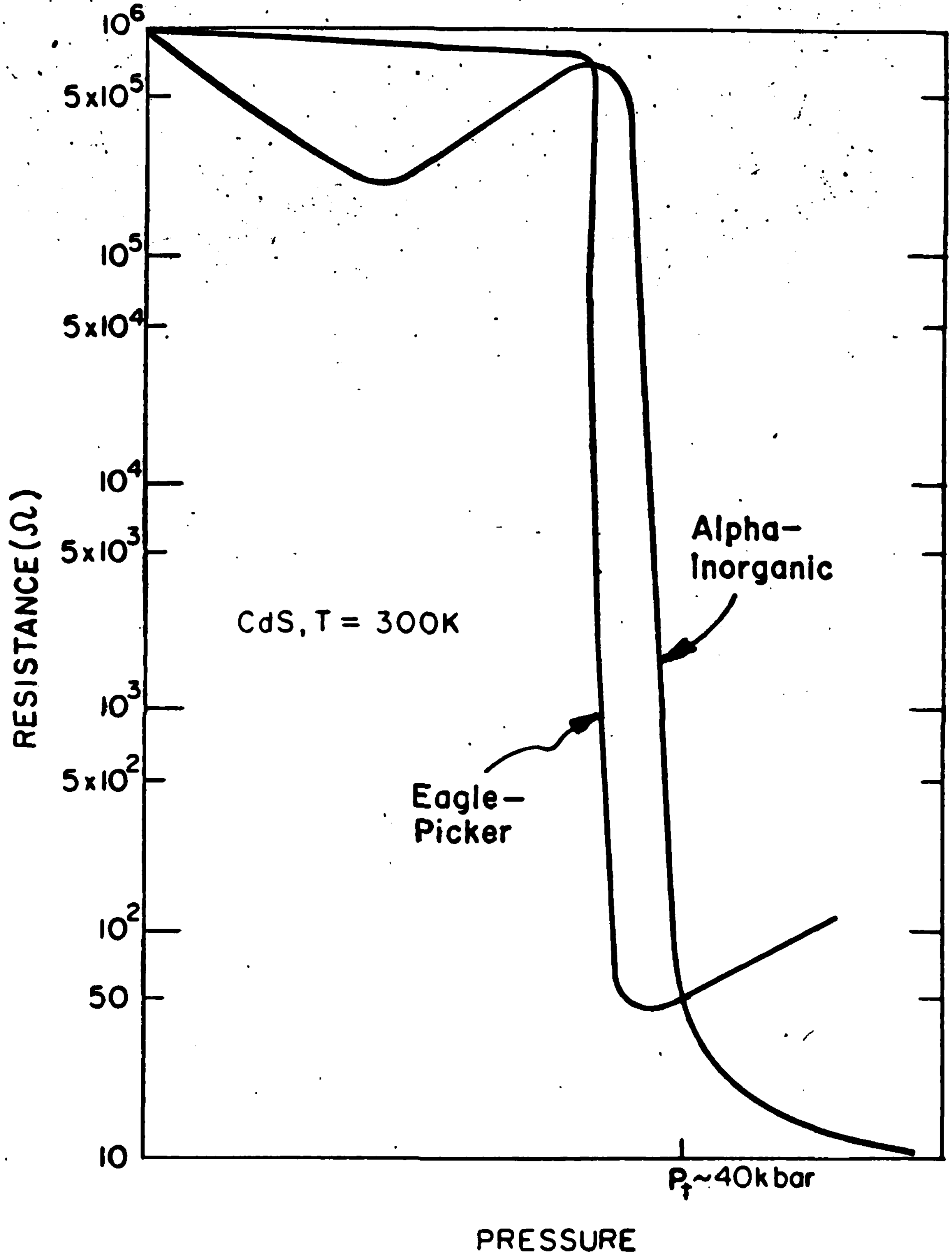



$Pd_x M_{1-x} H$
Cu
Au
Ag
Ag
20
18
16
14
12
10
8
6
4
2
25
50
75
T_c (K)
NOBLE METAL CONC. (at %)

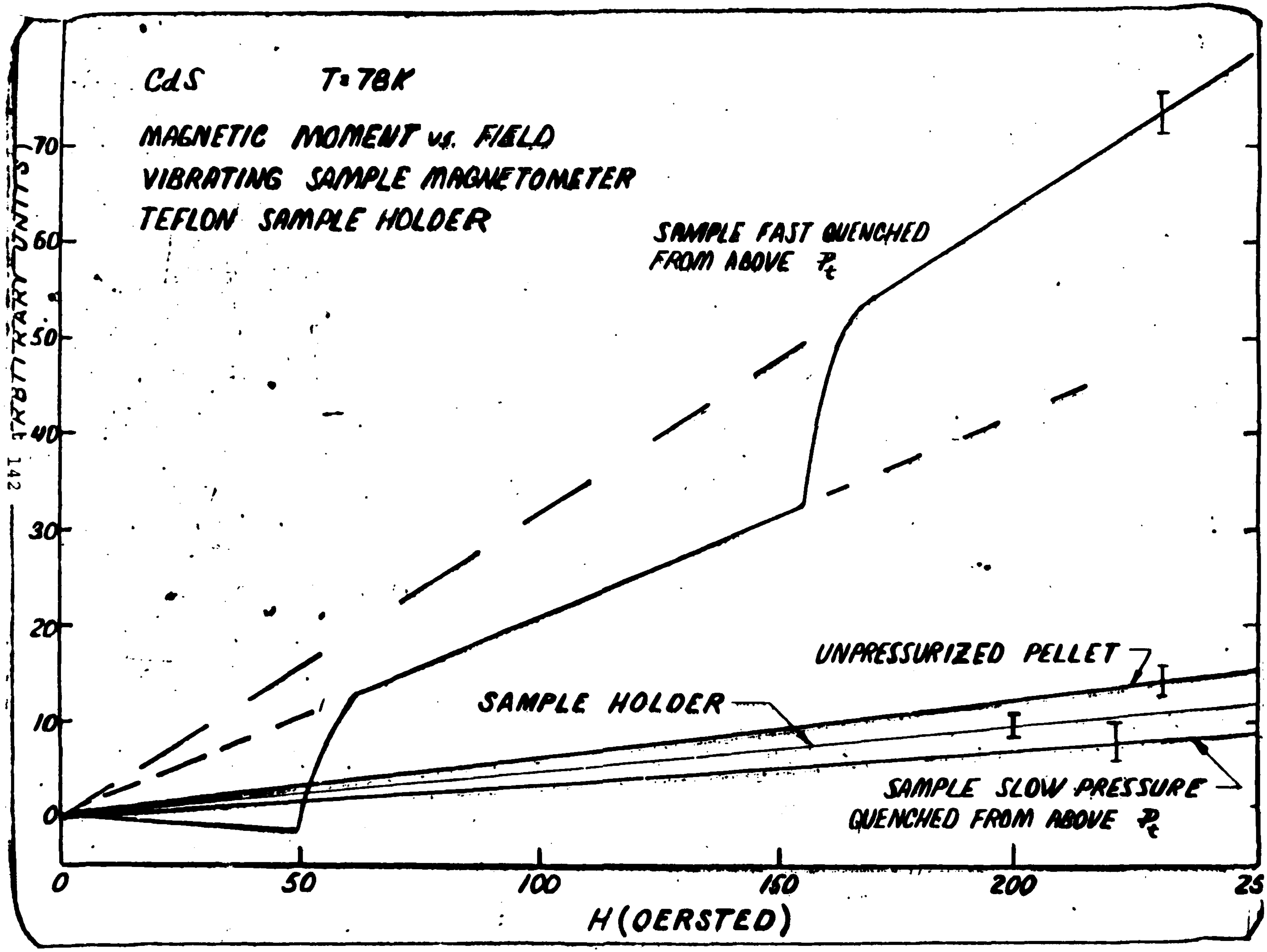


Polycrystalline CdS pellet before (left, translucent orange) and after (right, opaque black) pressure quenching from 50 Kbars at about 10^6 bars/sec. (Millimeter scale at bottom for size comparison.)

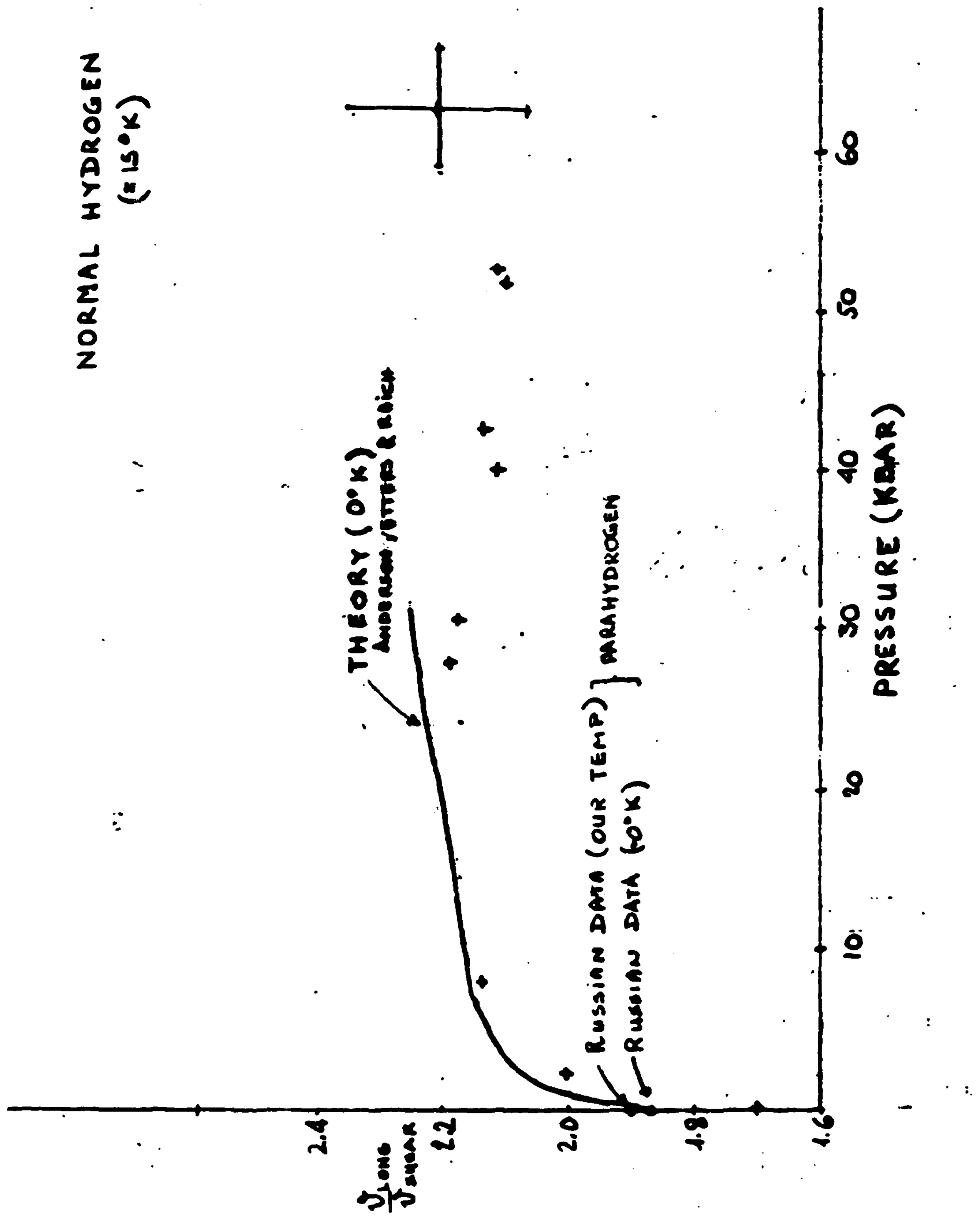
HIGH PRESSURE SYNTHESIS OF A METASTABLE FORM OF CADMIUM SULFIDE



Pressure vs. resistance of two grades of CdS. The alpha inorganic material is the material which shows anomalous magnetic properties.



CdS T=78K
MAGNETIC MOMENT vs. FIELD
VIBRATING SAMPLE MAGNETOMETER
TEFLON SAMPLE HOLDER
SAMPLE FAST QUENCHED FROM ABOVE P_t
UNPRESSURIZED PELLET
SAMPLE HOLDER
SAMPLE SLOW PRESSURE QUENCHED FROM ABOVE P_t
H(OERSTED)
0
50
100
150
200
25
10
20
30
40
50
60
70


NORMAL HYDROGEN
(≈15°K)
THEORY (0°K)
ANDERSON /ETTERS & RAICH
RUSSIAN DATA (OUR TEMP)
RUSSIAN DATA (0°K)
PARAHYDROGEN
PRESSURE (KBAR)
10
20
30
40
50
60
V LONG / V SHEAR
1.6
1.8
2.0
2.2
2.4

METALLIC HYDROGEN

HIGH TEMPERATURE SUPERCONDUCTOR

HIGH CRITICAL FIELD (Hc)

LOW DENSITY

25 TIMES MORE ENERGY THAN HIGH EXPLOSIVES

METALLIC HYDROGEN
THEORETICAL PREDICTIONS

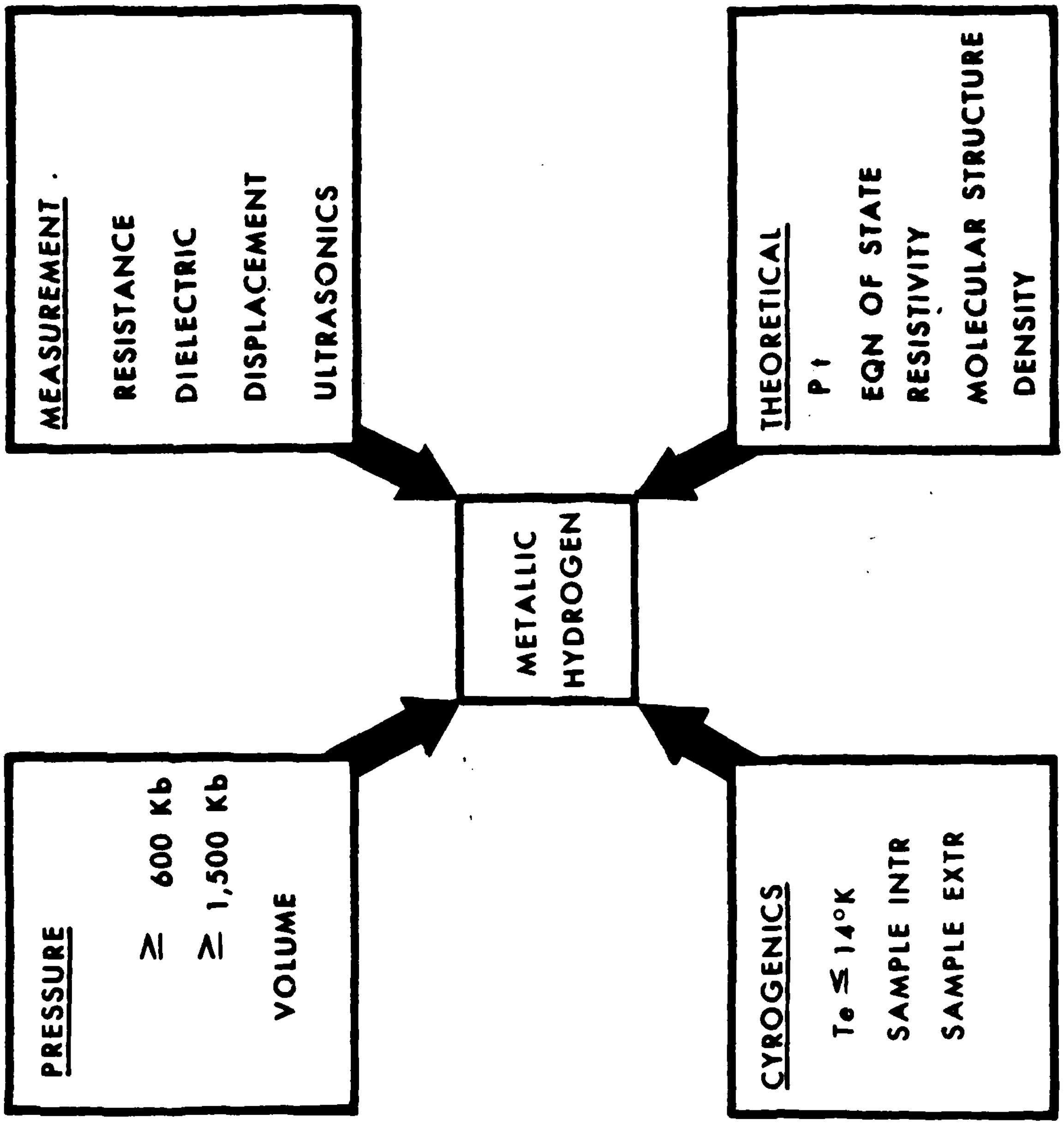
MOLECULAR → METALLIC TRANSFORMATION PRESSURE — 800 Kb → 5,000 Kb

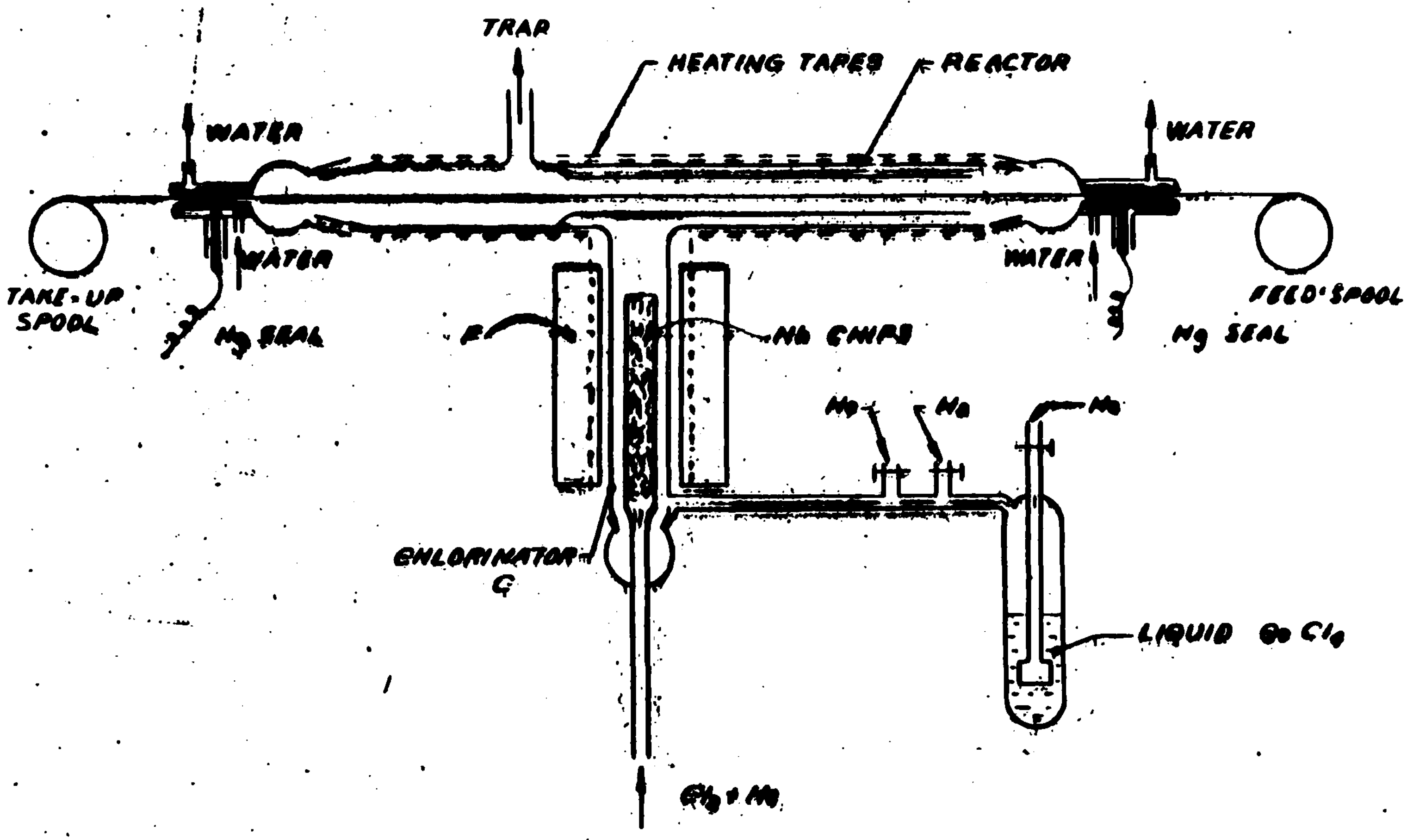
METASTABILITY — 0 → 0.2 ev

SUPERCONDUCTIVITY — (Tc) — O°K → 242°K

DENSITY — 0.89 gm/cm^3 → 1.6 gms/cm^3

STRUCTURE — FCC, HCP, BCC


MEASUREMENT
RESISTANCE
DIELECTRIC
DISPLACEMENT
ULTRASONICS
THEORETICAL
P ↑
EQN OF STATE
RESISTIVITY
MOLECULAR STRUCTURE
DENSITY
METALLIC
HYDROGEN
PRESSURE
≥ 600 Kb
≥ 1,500 Kb
VOLUME
CYROGENICS
Te ≤ 14°K
SAMPLE INTR
SAMPLE EXTR



Chemical vapor deposition technique for coating A15 material on filaments.

COPPER CHLORIDE; STABILITY AND EXCITON POPULATION PERCURSIVE TO ANOMALOUS DIAGMAGNETISM

Presented by I. Lefkowitz
U. S. Army Research Office, Research Triangle Park, NC 27709,
and Hunter College of the City University of New York, NY 10021,
and University of North Carolina, Chapel Hill, NC 27514

ABSTRACT

Single crystal, and disordered CuCl has been studied as a function of exciton density and temperature. Large changes in the electrical properties have been observed. We will report on evidence that such changes are reproducible and correlate with exciton density. Primary attention will be given to the question of chemical stability. Evidence will be presented that no chemical changes (disproportionation) has occurred after many temperature cycles from 11°K to R.T. with and without high exciton population density. Changes in the dielectric and magnetic properties that have been observed will be discussed in light of the high temperature superconductivity theory of Ginsberg, Kirsnitz, Lefkowitz and Bloomfield.

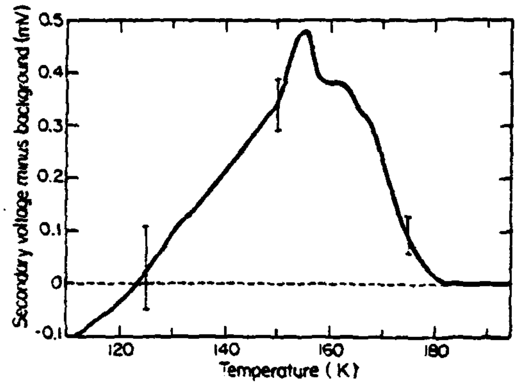


FIG. 1. This figure shows the deviation of the secondary voltage beyond background drift as a CuCl sample was warmed under 5 kbar pressure. The positive deviation indicates increased diamagnetism. The error bars indicate uncertainty in the background. The secondary voltage deviated from the background only between 120 and 180 K.

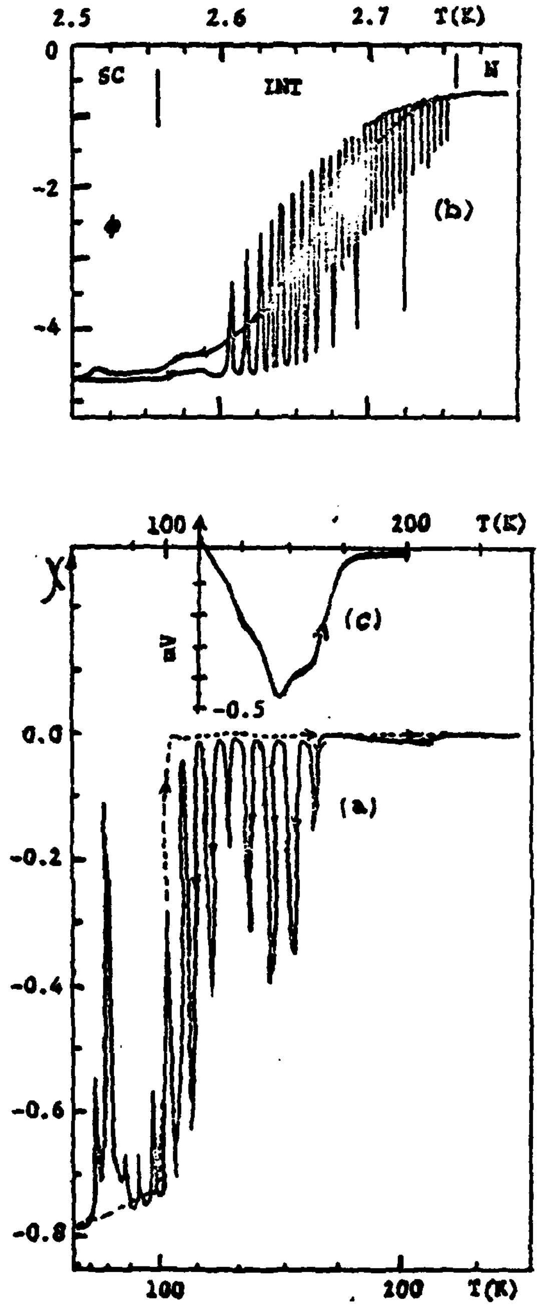


FIG. 3. Oscillatory susceptibility behavior: (a) the differential magnetic susceptibility observed at 20 Hz in CuCl redrawn from Brandt *et al.*, Ref. 6; (b) negative of phase change observed in secondary coil during 100 Hz susceptibility measurement in americium redrawn from Olsen. (Ref. 10); SC: superconducting. INT: intermediate state. N: normal; (c) work reported herein redrawn on the same (logarithmic) temperature scale as Brandt *et al.*, (Ref. 6).

These figures

Figures previously published in: Diamagnetic Transition in Disorded CuCl. Lefkowitz, I.; Manning, J.S.; Bloomfield, P.E.; Phys Rev B, 20(11). Dec. 1, 1979.

[6]N. B. Brandt, S. V. Kuvschinnikov, A. P. Rusakov, and M. V. Semenov, JETP Lett. 27, 37 (1978).

[10]C. E. Olsen, Phys. Lett. 43A, 205 (1973).

NAVY SUPERCONDUCTIVE MACHINERY DEVELOPMENT PROGRAM

Presented by Michael Superczynski
David W. Taylor Naval Ship Research
and Development Center

ABSTRACT

The Navy is developing the technology base for superconducting electric propulsion machinery systems for ship drives in the range of 40,000 to 75,000 hp per shaft. Full scale system development is aimed at the 1983-88 period. Current progress includes design, construction and tests of laboratory superconductive machinery in the 400 to 1000 hp range, preliminary design of 40,000 hp systems and ongoing construction and tests of 3000 hp feasibility models of full scale systems.

Advanced development of superconductive electric ship propulsion systems was started in fiscal year 1973. The impetus for developing the technology for these ship propulsion systems originates in the research and exploratory development studies of several Navy activities and the Defense Advanced Research Projects Agency beginning in the mid 1960's. These studies convincingly showed the potential effectiveness of compact and efficient superconductive propulsion systems as compared to turbine-gear or conventional electric machinery.

The prime contractors involved in the construction of 3000 hp machinery are AiResearch and General Electric. AiResearch is constructing: 1) two normally conducting a.c. alternators and solid state rectifier assemblies, 2) one d.c. superconductive homopolar motor. All equipments are basically complete and undergoing no load factory test. Delivery is expected to begin in June 1980. General Electric is constructing two superconductive homopolar motors, each of somewhat different design. The first is now complete and undergoing factory no load testing with expected delivery in 4th quarter FY 80. The second motor is approximately 70% complete and expected delivery in FY 81.

The DTNSRDC 400 hp superconductive motor and generator propulsion system is being installed on the 65 foot test craft, Jupiter II, to be tested in the Chesapeake Bay in 4th quarter FY 80.

Cryogenic cooling for these systems will be provided by CTl 1400 liquefiers in the laboratory and the NRL #1 unit on take test craft. This unit was built by Dr. Sam Collins at NRL and shows a significant improvement in efficiency.

In addition to these contractor efforts there is a significant in-house technology development effort, approximately 20 MY/yr, in the areas of machinery evaluation, current collectors, superconductive magnets, switchgear and transmission lines, refrigeration, instrumentation, system analysis and application studies.

SUPERCONDUCTING MATERIALS PROGRAM AT NRL

Presented by D. U. Gubser
Naval Research Laboratory
Washington, D. C.

ABSTRACT

Superconducting materials research at NRL presently contains three major thrusts: 1) inhomogeneous superconductors, 2) homogeneous film superconductors, and 3) multifilamentary wire development. In the inhomogeneous superconductor studies, we are examining the superconducting properties of granular two dimensional NbN films. These investigations have revealed a critical fluctuation region near a characteristic temperature where the grains become phase coherently coupled due to the Josephson interaction. Studies of this phase coherent state are being systematically performed as functions of electric field, magnetic field, temperature and intergranular coupling strength. Future studies will involve V_3Ga and V_3Si compounds and new inhomogeneous structures.

Our homogeneous film studies involve the use of an ultra high vacuum sputtering facility for producing high Tc compound materials. The films are subsequently characterized by diffractometry and Auger analysis to determine crystal structure and chemical composition. Superconducting properties are then measured and correlated with film quality and fabrication conditions. These procedures were used on the NbC_xN_{1-x} pseudobinary system with a resulting improvement of T_c values to that previously reported only on bulk samples, namely T_c (max) of 17.8 K. A transition width of only 0.02 K was observed in this film. Future work on homogeneous films will concentrate on V_3Ga and V_3Si compounds due to their intrinsically high thermodynamic critical field values H_c which are higher than any other known superconductor.

Our multifilamentary wire program has concentrated on the superconducting compound V_3Ga which is formed into wire by a modified bronze technique where both the Cu bronze matrix and the V-Ga core rods are alloyed. This process produces wire with Jc values higher than any other wire at 4.2 K and in fields from 3 to 18 tesla. V_3Ga wire is also slightly more radiation and strain resistant than Nb_3Sn wire. A contract for the production of 500 meter lengths of 25,000 filament V_3Ga wire has been given to AIRCO and delivery date is anticipated this summer.

SUPERCONDUCTING MATERIALS

DON GUBSER

STU WOLF

TOM FRANCAVILLA

DAVE JONES

RUSS MEUSSNER

DAVE HOWE

CRYOGENIC REFRIGERATION

SAM COLLINS

MAJOR PARTICIPANTS IN NRL'S SUPERCONDUCTING MATERIALS & CRYOGENIC REFRIGERATION EFFORTS

- INHOMOGENEOUS SUPERCONDUCTORS

  NbN V_3Ga

- HOMOGENEOUS FILM SUPERCONDUCTORS

  NbN, Nb(CN), V_3Ga

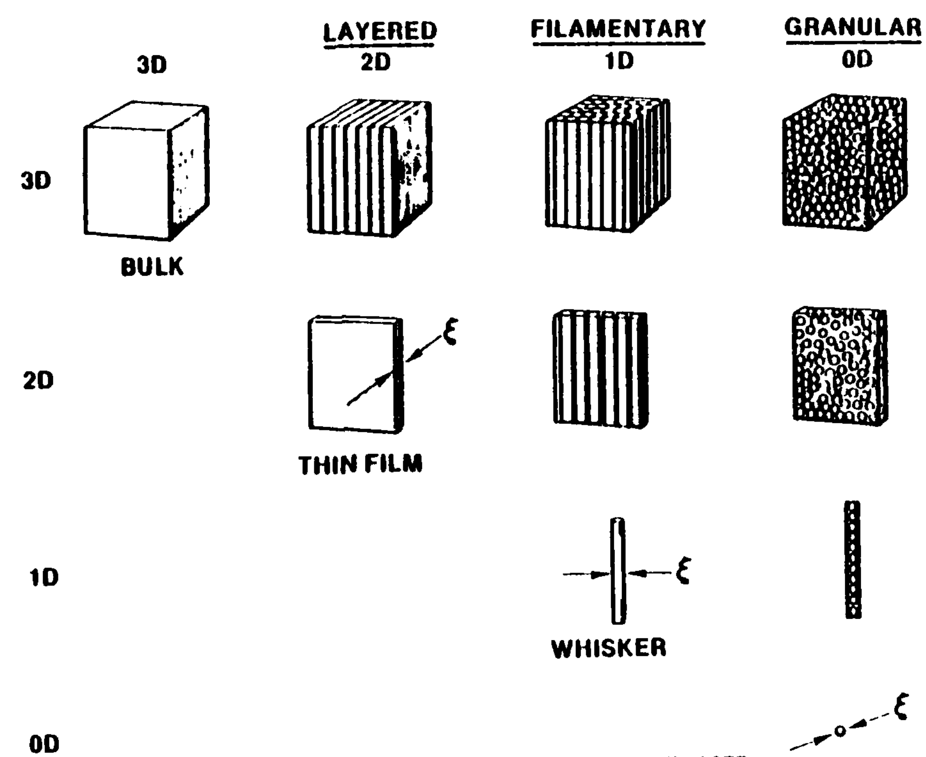
- MULTIFILAMENTARY WIRE

  V_3Ga

3 MAJOR THRUSTS OF NRL'S SUPERCONDUCTING MATERIALS PROGRAM. LISTED UNDER THE MAJOR THRUST ARE THE SPECIFIC MATERIALS PRESENTLY BEING INVESTIGATED.

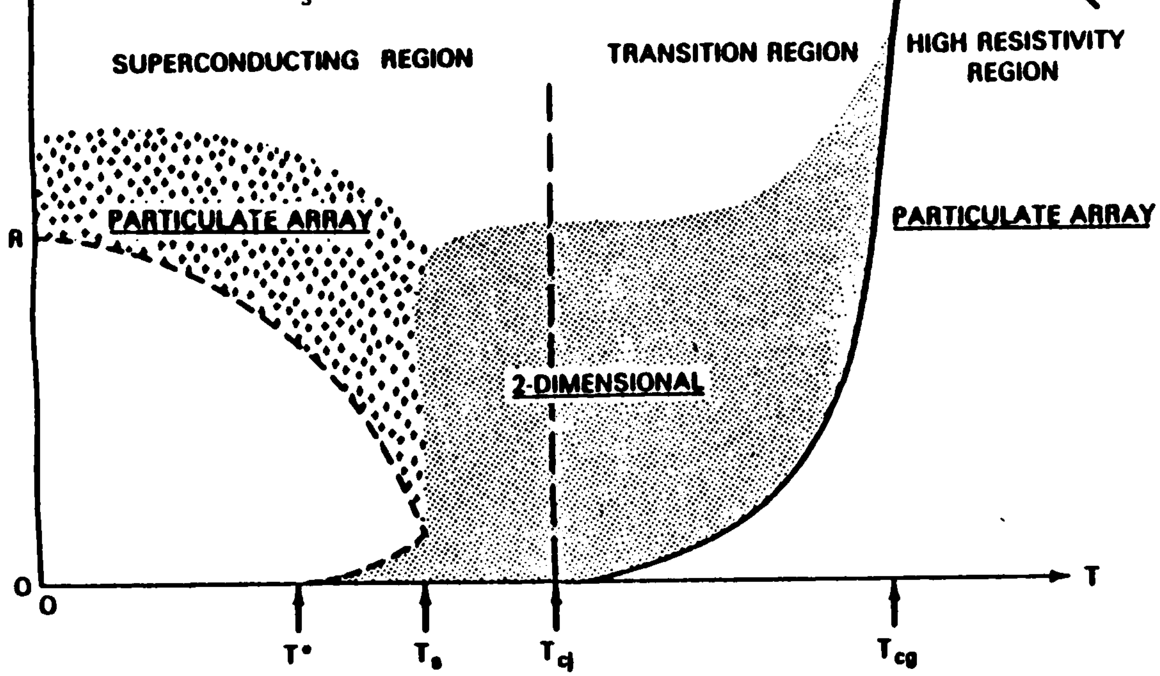
DIMENSIONALITY IN SUPERCONDUCTORS

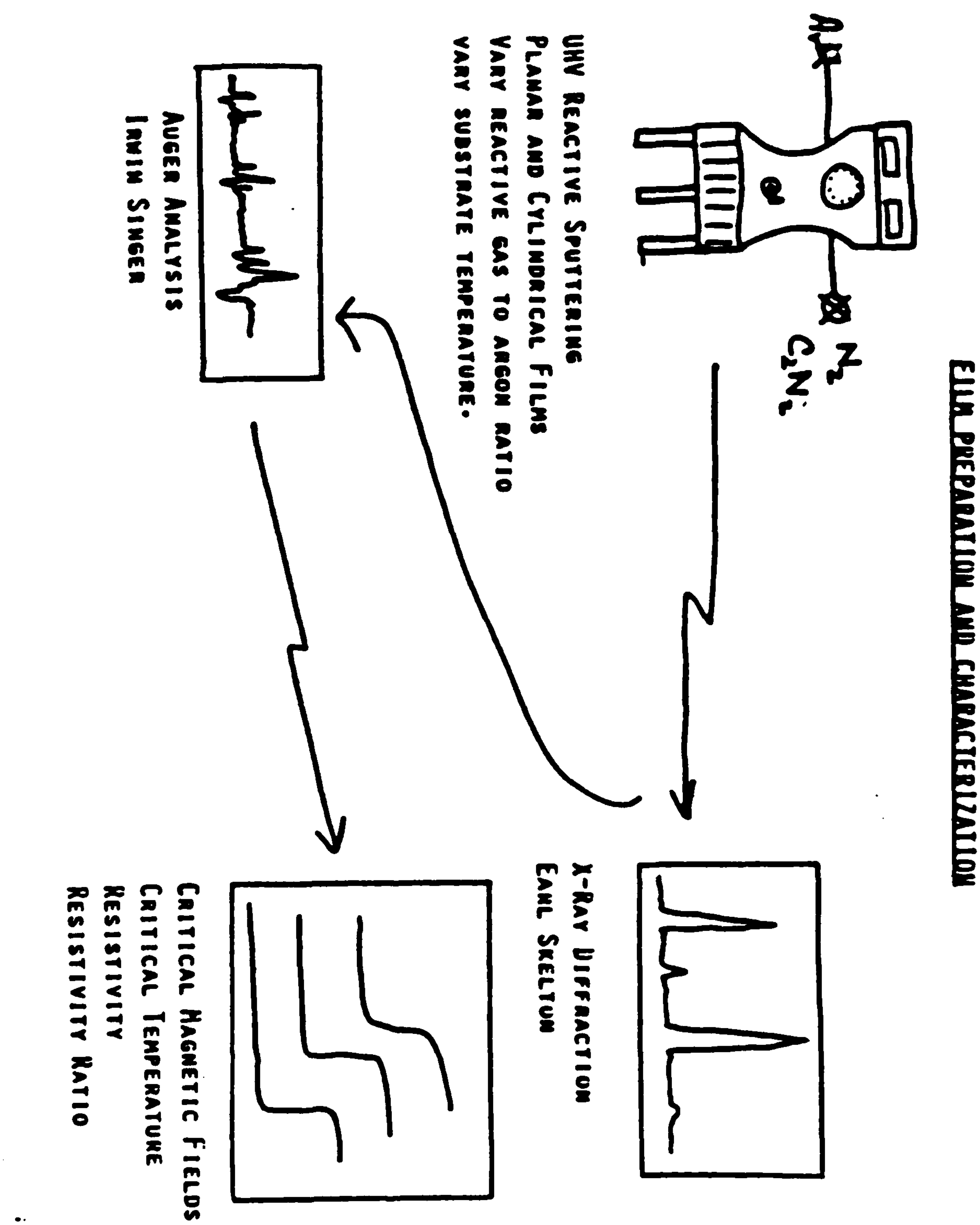
INHOMOGENEOUS SYSTEMS



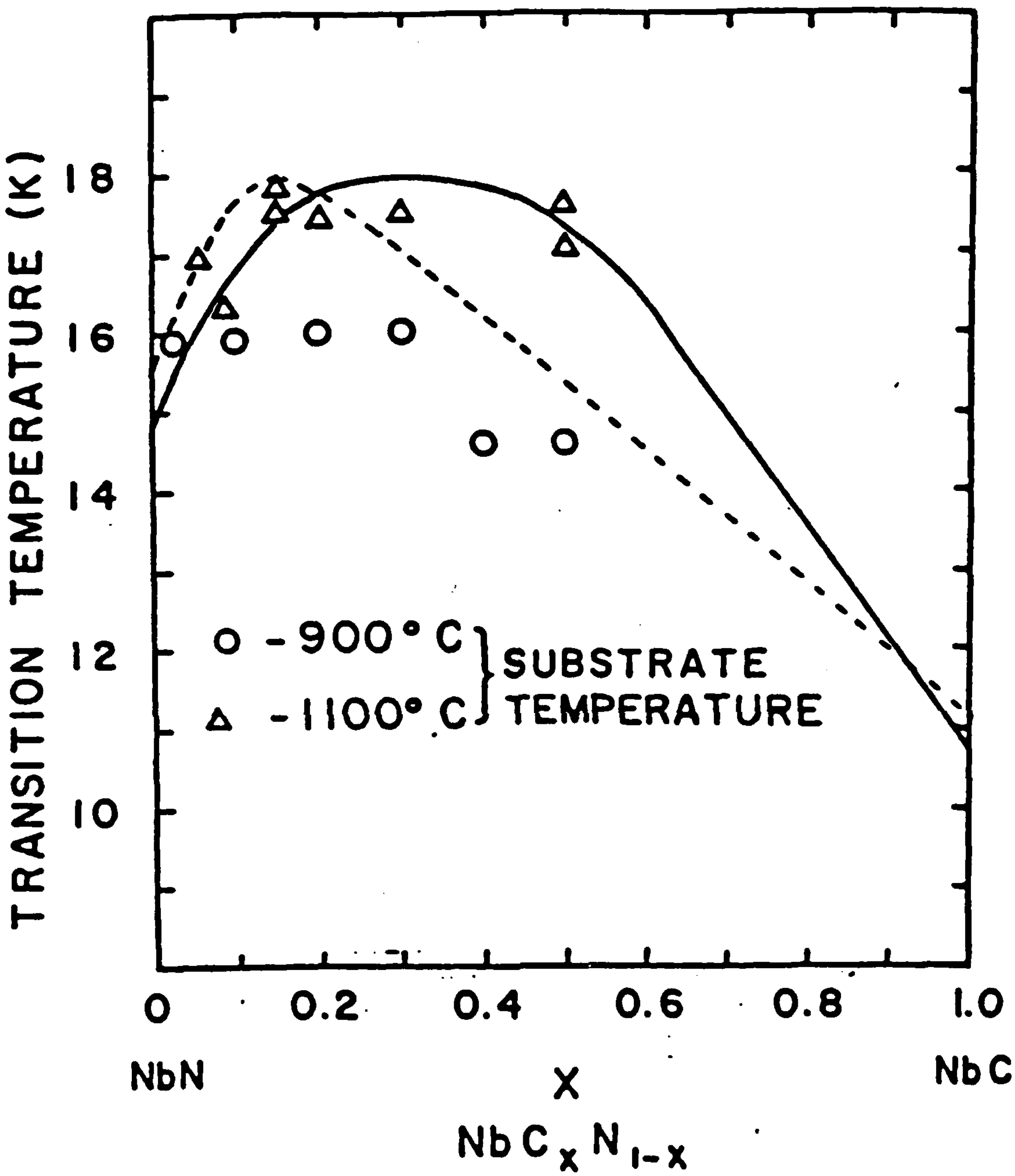
THE INHOMOGENEOUS SUPERCONDUCTING CLASS OF MATERIAL ARE COMPOSITE STRUCTURES COMPOSED OF SUPERCONDUCTING REGIONS WITH AT LEAST ONE DIMENSION SMALL IMBEDDED IN A NONSUPERCONDUCTING MATRIX. AT NRL WE HAVE CONCENTRATED ON THE 2 DIMENSIONAL GRANULAR STRUCTURE COMPOSED OF NbN GRAINS IN A Nb_2O_5 INSULATING MATRIX.

RESISTANCE vs TEMPERATURE OF A TWO-DIMENSIONAL GRANULAR NbN SPECIMEN. BETWEEN T_{CG} AND T_S, NbN ACTS LIKE A HOMOGENEOUS TWO-DIMENSIONAL CONDUCTOR. SHADED AND CROSS-CHECKED REGIONS REPRESENT CURRENT-DEPENDENT RESISTANCE REGIMES. SOLID LINE IS THE RESISTANCE MEASURED AT LOW CURRENT DENSITIES; DASHED LINE ENCLOSES THE REGION OF ZERO RESISTANCE. NOTE THE SMALL RESISTANCE AT THE LOW CURRENTS IN THE TEMPERATURE RANGE T_S TO T^*.





NRL THIN FILMS FOR BOTH THE INHOMOGENEOUS AND HOMOGENEOUS PROGRAMS ARE PREPARED BY REACTIVE SPUTTERING FOLLOWED BY CAREFUL STRUCTURAL, CHEMICAL, ELECTRICAL, AND SUPERCONDUCTING MEASUREMENTS.



RECENT WORK ON THE NbC_xN_{1-x} SYSTEM HAS LED TO THE FORMATION OF THIN FILMS WITH T_c's UP TO 17.8 K($\Delta T_c \approx 20$ mK), WHICH IS EQUAL TO THE HIGHEST REPORTED BULK VALUE.

HIGH T_C SUPERCONDUCTORS SHOWING T_C, H_{C2}, AND H_C VALUES. THE LAST COLUMN SHOWS THAT $H_C(0)$ OF V_3Ga IS THE HIGHEST OF ANY KNOWN SUPERCONDUCTING MATERIAL WITH V_3Si COMING IN A CLOSE SECOND. THIS IS DUE TO THE EXTREMELY HIGH ELECTRONIC DENSITY OF STATES AT THE FERMI LEVEL $N(E_F)$ IN V_3Ga AND V_3Si.

COMPOUND (NOMINAL)	STRUCTURE	T_o (K)	H_{C2}(4.2K) TESLA	H_C (0) TESLA
Nb_3Ge	A15	23.3	37.0	0.48
$Nb_{3.2}[Ge_{.2}Al_{.6}]$	A15	20.7	41.0	
Nb_3Ga	A15	20.3	33.0	0.38
$Nb_3[Ga_{.5}Al_{.5}]$	A15	19.0	31.0	
Nb_3Al	A15	18.9	29.5	0.40
Nb_3Sn	A15	18.3	26.0	0.54
V_3Si	A15	17.1	23.0	0.58
V_3Ga	A15	15.4	23.6	0.60
$Pb_{1.0}MO_{5.1}S_6$	CHEVREL	14.4	51.0	
$Sn_{1.0}MO_{5.0}S_6$	CHEVREL	13.4	29.0	
Nb N	B1	16.0	15.0-29.0	0.20
$Nb[N_{0.7}C_{0.3}]$	B1	17.8	< 12.5(?)	
Nb Ti		9.1	~12.0	

NRL

- SUPERCONDUCTING CAVITIES AND RESONATORS

$$R_{wall} \propto \frac{\omega^n}{T} \, e^{-\frac{\Delta(o)}{KT}}$$

$$\longrightarrow H_c^{RF} \sim 0.8 H_c \longleftarrow$$ (High T_c superconductors)

- MULTIFILAMENTARY WIRES

$$J_c = \frac{K_s}{H} \, h^{\frac{1}{2}} (1-h)^2$$

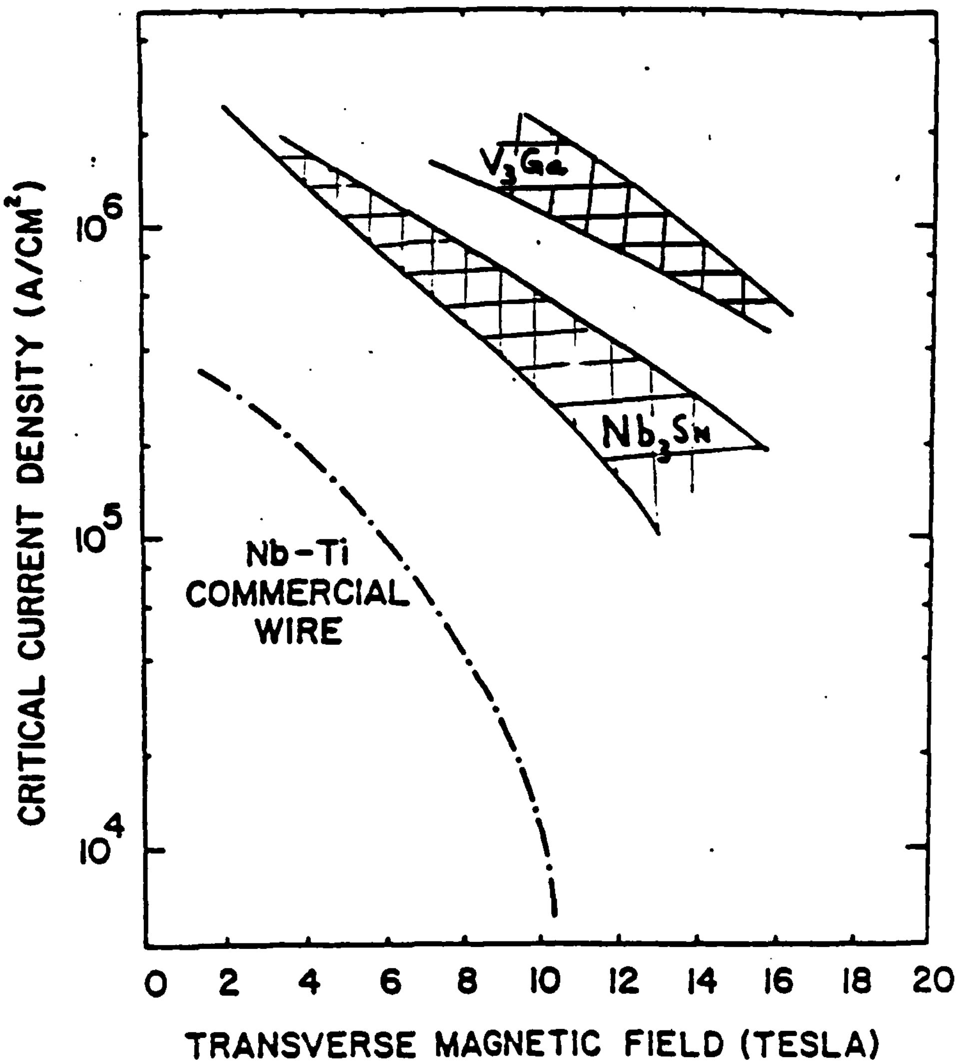
where $h = H/H_{c_2}$

$$\longrightarrow K_s \propto H_c^2 \; H_{c_2}^{\frac{1}{2}} \longleftarrow$$

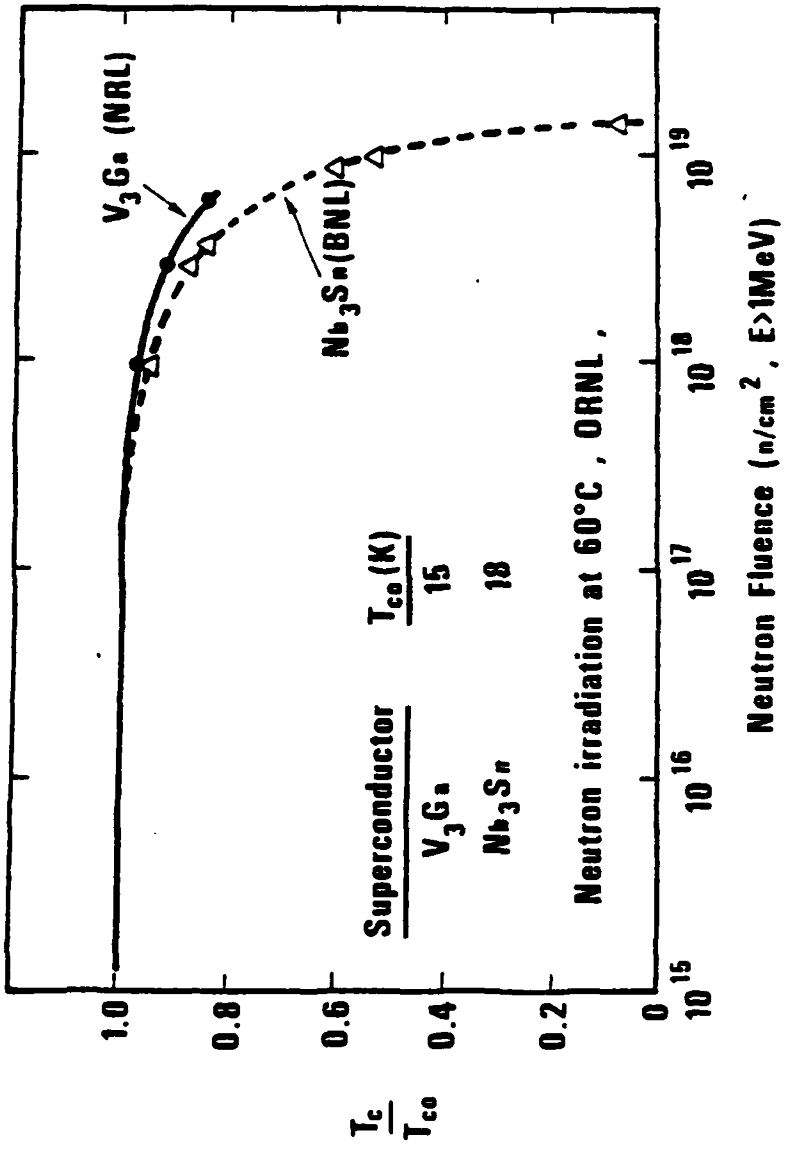
THE IMPORTANCE OF A HIGH H_c VALUE IS EMPHASIZED HERE FOR TWO APPLICATIONS. FOR SUPERCONDUCTING CAVITIES AND RESONATORS, ONE NEEDS A HIGH H_c VALUE SINCE THE CRITICAL RF FIELD H_cRF AT WHICH EXCESSIVE WALL LOSSES OCCUR IS DIRECTLY PROPORTIONAL TO H_c IN THE HIGH T_c COMPOUNDS.

FOR SUPERCONDUCTING WIRE, ONE NEEDS A HIGH H_c VALUE SINCE THE AMOUNT OF CURRENT THAT A SUPERCONDUCTOR CAN CARRY IN HIGH MAGNETIC FIELDS DEPENDS ON H_c^2. THE HIGH H_c AND H_{c2} VALUE OF V_3Ga MAKE IT A FACTOR OF 2 BETTER THAN Nb_3Sn AT 4.2K AND 10 TESLA.

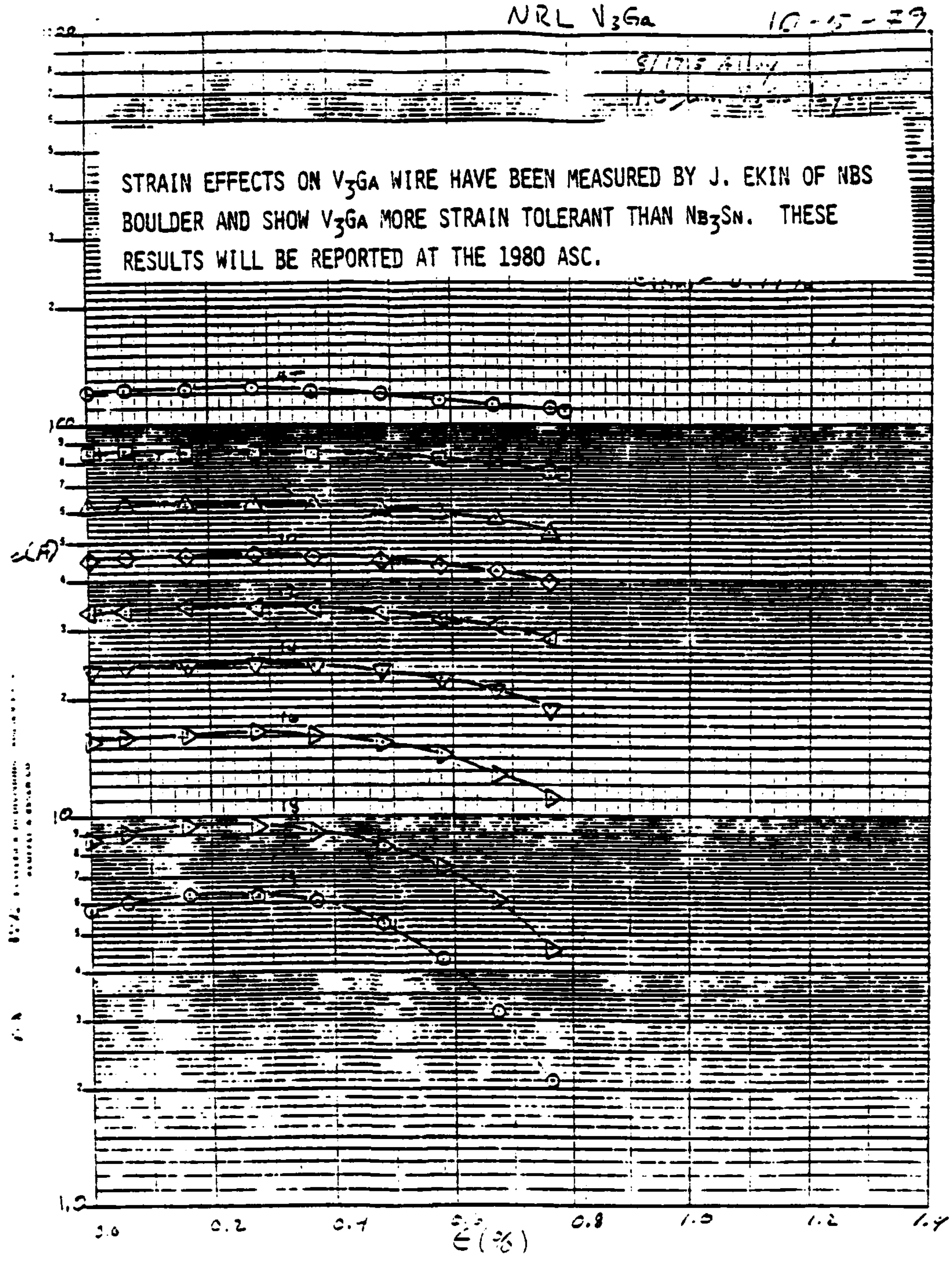
PLOT OF THE BEST REPORTED J_c VALUES AS A FUNCTION OF MAGNETIC FIELD FOR NbTi, Nb_3Sn AND V_3Ga. Nb_3Sn RESULTS ARE FROM WORK DONE AT BNL WHILE RESULTS FOR V_3Ga ARE FROM NRL. (SEE 1978 ASC).



COMPARISON OF RADIATION DAMAGE FOR Nb_3Sn AND V_3Ga SHOWING SIMILAR TRENDS, BUT SLIGHTLY LESS DEGRADATION OF T_c FOR A GIVEN NEUTRON FLUENCE IS NOTICES FOR V_3Ga.



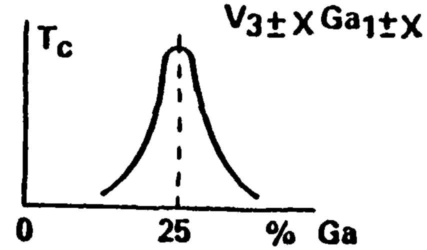
STRAIN EFFECTS ON V_3Ga WIRE HAVE BEEN MEASURED BY J. EKIN OF NBS BOULDER AND SHOW V_3Ga MORE STRAIN TOLERANT THAN Nb_3Sn. THESE RESULTS WILL BE REPORTED AT THE 1980 ASC.



(6.1)
BASIC STUDIES OF AIS

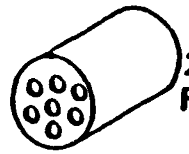
COMPOSITION
HOMOGENEITY
LONG RANGE ORDER

$\Longrightarrow$



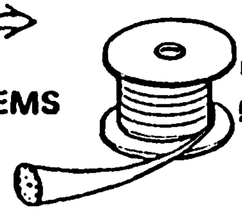
+

(6.1/6.2)
- FABRICATION TECHNIQUE
- GROWTH KINECTICS
- T_C, J_C (H,T), T_C (ϕ), J_C (σ)



$\Downarrow$

INDUSTRIAL CONTRACT $\Longrightarrow$



USEFUL CONDUCTOR FOR NAVAL SYSTEMS ENGINEERS (DELIVERY DATE JUNE,80)

- MOTORS, GENERATORS

NRL

NRL'S PROGRAM TO DEVELOP MULTIFILAMENTARY V_3Ga WIRE BEGAN WITH A BASIC RESEARCH STUDY ON THE COMPOUND $V_{3\pm x}Ga_{1\pm x}$ AND THEN PROCEEDED TO A STUDY OF FABRICATION TECHNIQUES AND SUPERCONDUCTING PROPERTIES OF V_3Ga WIRE FORMED BY A MODIFIED BRONZE TECHNIQUE WHEREIN BOTH THE Cu BRONZE MATRIX AND V CORE RODS ARE ALLOYED WITH Ga. AN INDUSTRIAL CONTRACT TO PRODUCE 500 METER LENGTHS OF 25,000 FILAMENT V_3Ga WIRE HAS BEEN GIVEN TO AIRCO WITH DELIVERY SCHEDULED FOR SUMMER 1980.

APPENDIX

List of

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